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ABSTRACT

This report summarizes and compares the views of six experts-three university professors and three elementary teacher-concerning elementary-level science teaching. The experts were asked to treat the topic comprehensively by addressing the following: (1) issues of curriculum (goals and objectives, selection and organization of content); (2) materials and instruction (presentation of input to students, teacher-student discourse, activities and assignments); (3) evaluation of student learning (formal and informal assessment of student progress toward key goals before, during, and after instruction); and (4) teacher education (subject matter knowledge, professional development). The experts addressed these issues in the context of both ideal programs (as outlined in their responses to a set of questions about what ideal curriculum, instruction, and evaluation practices in elementary science programs would look like) and typical current practice (as outlined in their responses to questions calling for critique of one of the most widely adopted elementary science curriculum series). This report first summarizes the positions articulated by each of the six experts considered individually, then describes areas of agreement and disagreement across the six experts. These comparisons are then considered with reference to their implications concerning ideal elementary science programs. The key features of ideal science curricula and the framing questions used in this report are appended. (Author/KR)

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EXPERTS' VIEWS ON THE ELEMENTARY SCIENCE CURRICULUM: VISIONS OF THE IDEAL

Kathleen J. Roth, David C. Eichinger,
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Center for the Learning and Teaching of Elementary Subjects

Institute for Research on Teaching
College of Education
Michigan State University

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Center for the Learning and Teaching of Elementary Subjects

The **Center for the Learning and Teaching of Elementary Subjects** was awarded to Michigan State University in 1987 after a nationwide competition. Funded by the Office of Educational Research and Improvement, U.S. Department of Education, the Elementary Subjects Center is a major project housed in the Institute for Research on Teaching (IRT). The program focuses on conceptual understanding, higher order thinking, and problem solving in elementary school teaching of mathematics, science, social studies, literature, and the arts. Center researchers are identifying exemplary curriculum, instruction, and evaluation practices in the teaching of these school subjects; studying these practices to build new hypotheses about how the effectiveness of elementary schools can be improved; testing these hypotheses through school-based research; and making specific recommendations for the improvement of school policies, instructional materials, assessment procedures, and teaching practices. Research questions include, What content should be taught when teaching these subjects for understanding and use of knowledge? How do teachers concentrate their teaching to use their limited resources best? and In what ways is good teaching subject matter-specific?

The work is designed to unfold in three phases, beginning with literature review and interview studies designed to elicit and synthesize the points of view of various stakeholders (representatives of the underlying academic disciplines, intellectual leaders and organizations concerned with curriculum and instruction in school subjects, classroom teachers, state- and district-level policymakers) concerning ideal curriculum, instruction, and evaluation practices in these five content areas at the elementary level. Phase II involves interview and observation methods designed to describe current practice, and in particular, best practice as observed in the classrooms of teachers believed to be outstanding. Phase II also involves analysis of curricula (both widely used curriculum series and distinctive curricula developed with special emphasis on conceptual understanding and higher order applications), as another approach to gathering information about current practices. In Phase III, models of ideal practice will be developed, based on what has been learned and synthesized from the first two phases, and will be tested through classroom intervention studies.

The findings of Center research are published by the IRT in the Elementary Subjects Center Series. Information about the Center is included in the IRT Communication Quarterly (a newsletter for practitioners) and in lists and catalogs of IRT publications. For more information, to receive a list or catalog, or to be placed on the IRT mailing list to receive the newsletter, please write to the Editor, Institute for Research on Teaching, 252 Erickson Hall, Michigan State University, East Lansing, Michigan 48824-1034.

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Abstract

This report summarizes and compares the views of six experts--three university professors and three elementary teachers--concerning elementary-level science teaching. The experts were asked to treat the topic comprehensively by addressing issues of curriculum (goals and objectives, selection and organization of content), materials and instruction (presentation of input to students, teacher-student discourse, activities and assignments), evaluation of student learning (formal and informal assessment of student progress toward key goals before, during, and after instruction), and teacher education (subject matter knowledge, professional development). The experts addressed these issues in the context of both ideal programs (as outlined in their responses to a set of questions about what ideal curriculum, instruction, and evaluation practices in elementary science programs would look like) and typical current practice (as outlined in their responses to questions calling for critique of one of the most widely adopted elementary science curriculum series). This report first summarizes the positions articulated by each of the six experts considered individually, then describes areas of agreement and disagreement across the six experts. These comparisons are then considered with reference to their implications concerning ideal elementary science programs.

EXPERTS' VIEWS ON THE ELEMENTARY SCIENCE CURRICULUM: VISIONS OF THE IDEAL

Kathleen J. Roth, David C. Eichinger, Susan I. McMahon, and Richard S. Prawat[1]

Research on science teaching and learning has caused concern about what elementary children are learning (and not learning) about science. What opportunities do students have to learn science when science is not taught regularly across the K-6 span and when teachers avoid science teaching because of lack of confidence in their knowledge? However, what is the point of teaching elementary science if it is not helping students develop meaningful, useful understandings of science concepts and of the nature of scientific thinking? Classroom studies of student learning demonstrate that elementary science textbooks emphasize vocabulary memorization over genuine conceptual development. The research also demonstrates that abandonment of the textbook in favor of hands-on activities and explorations is not the solution to children's learning problems. Hands-on work does not assure learning and higher level thinking. Students can participate in hands-on work without changing or deepening their ways of thinking. In fact, students in some activity-oriented classrooms develop troubling views of science as mysterious and nonsensical--scientists are always doing experiments and measuring and graphing but why (Roth, 1989)?

Is it possible to teach science to elementary students in ways that support the development of conceptual understanding? Can the elementary science

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[1]Kathleen J. Roth, assistant professor of teacher education at Michigan State University, is a senior researcher with the Center for the Learning and Teaching of Elementary Subjects. David A. Eichinger, currently an assistant professor of science education at Purdue University, was a research assistant with the Center. Susan I. McMahon, an assistant professor in reading at the University of Wisconsin-Madison, was a research associate with the Center. Richard S. Prawat, professor of teacher education and senior researcher with the Center, coordinated the comprehensive study across school subjects.

curriculum help students develop knowledge that they can use to explain phenomena in their experience? Some argue that it might be better to avoid science teaching in the elementary school. Others have visions of an elementary science curriculum that supports students in developing meaningful understanding of science and science concepts. Their visions come both from research efforts and from teaching experience. In this study, we tapped the visions of the ideal elementary science curriculum held by three university experts and three teacher experts. Looking at the similarities and differences among their visions of what is possible in elementary science programs provides insights into promising directions for curricular change, curriculum materials development, classroom teaching, and teacher education.

Background and Content for This Study

This report summarizes and compares the views of six experts--three university professors and three elementary teachers--concerning elementary-level science teaching. The experts were asked to treat the topic comprehensively by addressing issues of curriculum (goals and objectives, selection and organization of content), instruction (presentation of input to students, teacher-student discourse, activities and assignments), evaluation of student learning (formal and informal assessment of student progress toward key goals before, during, and after instruction), and teacher education (subject matter knowledge, professional development). The experts addressed these issues in the context of both ideal programs (as outlined in their responses to a set of questions about what ideal curriculum, instruction, evaluation, and teacher education, practices in elementary science programs would look like) and typical current practice (as outlined in their responses to questions calling for critique of one of the most widely adopted elementary science curriculum series).

This research is part of Phase I of the research agenda of the Center for the Learning and Teaching of Elementary Subjects. Center researchers are engaged in a five-year program of research and development on elementary-level (Grades K-6) teaching of mathematics, science, social studies, literature, and the arts, with particular emphasis on the teaching of these content areas for understanding and for application to problem solving or decision making. Phase I of the work relies on literature review and survey and interview methods to elicit and compare the views of various categories of experts (specialists in the academic disciplines, professional organizations concerned with the teaching of particular school subjects, state and local education agencies, curriculum designers, and university professors and elementary teachers with special interest and expertise in the school subjects addressed) concerning ideal curriculum, instruction, and evaluation practices in each subject. Phase II of the work switches focus from the intended curriculum to the enacted curriculum. This phase features development of detailed case studies of exemplary practice, relying on classroom observation and interviews of both teachers and students. Phase III of the work features improvement-oriented studies, in which ideas developed in earlier phases are being used as the basis for experimental interventions designed to improve content teaching within the limits of what can be accomplished given the constraints within which elementary teachers work.

Phase I work has been accomplished through a set of related studies. One of these studies involved developing and using a common set of framing questions to elicit the views of each of two sets of experts--university professors involved with the scholarship and teacher education aspects of elementary-level teaching in a school subject and elementary teachers with reputations for excellence in teaching the subject--on how each of our target

school subjects might be taught most effectively for understanding and higher order applications of its content. This report focuses on the views of the experts in science. Other reports from this work will focus on the views of experts in the elementary teaching of mathematics, social science, literature, the visual arts, and music, respectively, and a summary report will compare and contrast the views expressed by experts in these different subject areas.

Theoretical Perspective

The Center's mission focuses on issues surrounding the teaching of elementary subjects in ways that promote students' understanding of their content, ability to think about it critically and creatively, and ability to apply it in problem-solving and decision-making contexts. Review and synthesis of the literature on this topic, both as it applies to subject-matter teaching in general (Brophy, 1990; Prawat, 1989) and as it applies to the teaching of science in particular (Roth, 1990), identified the following as features of ideal elementary curriculum and instruction: (a) the curriculum balances breadth with depth by addressing limited content but developing this content sufficiently to foster conceptual understanding; (b) the content is organized around a limited number of powerful ideas (basic understandings and principles); (c) teaching emphasizes the relationships or connections between these ideas (integrated learning); (d) students regularly get opportunities to actively process information and construct meaning; and (e) higher order thinking skills are not taught as a separate skills curriculum but instead are developed in the process of teaching subject-matter knowledge within application contexts that call for students to relate what they are learning to their lives outside of school by thinking critically or creatively about it or using it to solve problems, make decisions, or construct explanations. The experts interviewed for this study were asked to critique, qualify, and extend

these ideas about features of ideal subject-matter teaching. Then they were asked to apply their views about ideal practices by telling us how they would go about teaching certain content and by critiquing one of the most widely adopted contemporary curriculum series in their subject area.

Identification and Recruitment of Experts

Two panels of science experts were recruited. The first panel consisted of three university-based professors of science curriculum and instruction who are internationally recognized scholarly leaders in the field and are particularly knowledgeable about elementary-level instruction in the subject area. These experts were identified as follows. First, science specialists both at Michigan State University and at other universities (contacted by phone) were asked to nominate individuals who were (a) scholarly leaders in the field; (b) familiar with curriculum, instruction, and evaluation practices in elementary-grade classrooms; and (c) concerned about teaching science with an emphasis on developing understanding, critical thinking, and application to problem solving or decision making. Next, we winnowed the longer lists to a short, prioritized list of desirable interviewees based in part on the information we had gathered about the degree to which they fit the three criteria mentioned above and in part on our desire to achieve balance across different philosophical positions on the nature and purposes of science education (preparing students to become research scientists, helping students develop conceptual understanding of the natural world, preparing science citizens). Once consensus on these short lists was achieved through discussion among Center researchers, we called the identified scholars to explain the study and attempt to recruit their participation.

The second panel consisted of three elementary school teachers who impressed leading science education scholars as being outstanding at teaching

science for understanding and higher order applications. To identify such teachers, we called scholarly leaders in science education at universities around the country (including those who were being recruited for participation in the study themselves) to describe the kinds of teachers we were seeking and to ask for nominations. We then contacted nominated teachers by phone and interviewed them concerning their educational backgrounds, teaching experience, and ideas about goals and methods for teaching science. Notes from these telephone interviews were then used as the basis for discussion of the relative desirability of different teachers for inclusion in the study. Continued discussion eventually yielded three prioritized short lists of nominees, one for teachers whose background experiences were concentrated in the primary grades, another for teachers representing Grades 3 and 4, and a third for teachers representing Grades 5 and 6. We then called the top-listed teachers to recruit their participation in the study, and were gratified to find that all of our first choices agreed to participate.

The Science Experts

Six experts participated in the analysis of the elementary science curriculum--3 university-based experts (P1, P2, and P3) and 3 teachers (T1, T2, and T3). The university experts were selected to represent a range of perspectives on the elementary science curriculum. This group included two researchers, one (P1) with a strong conceptual change orientation and the other (P2) with a significant background in the development and study of one of the hands-on, inquiry programs (Science Curriculum Improvement Study, Knott, Lawson, Karplus, Their, & Montgomery, 1987) of the post-Sputnik era. This expert meshes an inquiry perspective with current constructivist views of learning and is also particularly interested in the use of technological tools (especially the computer) in the science curriculum. The third

university-based expert (P3) is no longer a university researcher but is serving as associate director of a nonprofit science education center. His primary project at the time of the interview was the development and field testing of a new K-6 science series that presents an alternative to the traditional topics- centered science curriculum. This expert brings a strong interest in science, technology, and society issues to his analysis of the elementary science curriculum.

The teachers were selected to represent different grade levels and not necessarily different curricular perspectives. One teacher (T3) has an early primary focus and a master's degree in early childhood education. She currently teaches first grade in New York and has 13 years of experience with K-2 teaching and 7 years experience as a resource teacher for learning-disabled students. She completed graduate work beyond the master's to obtain special education certification. A third-grade teacher from Delaware (T1) and an upper elementary teacher from California (T2) are the other two teacher experts. T2 has taught middle school science as well as fourth and fifth grades. This teacher expert has a strong science background; he obtained a bachelor's and a master's degree in fisheries biology before entering the teaching profession.

The teachers were also selected because of their participation in different kinds of professional development activities. The California teacher has been active at the state level in development of the California K-8 Science Framework, in work on the state model curriculum guidelines, and in work on the state science assessment program. He is also active in the California Science Teachers Association. For the last two years, he has been a half-time science resource teacher for his district, supporting teachers in their teaching of science through workshops and in-classroom modeling and coaching. In this

role, T2 reviewed exemplary science programs across the country and led the development of science goals and curricula for his district.

The other teacher experts have been involved in research-focused projects with university science education experts. In these projects the teachers were involved in curriculum development work, study of research about science teaching and learning, and in-the-classroom coaching from university experts. In addition to receiving such coaching, T3 was also trained to be a support/ coach teacher for elementary schools in her region of New York state. In 1988 T3 was given an excellence in science teaching award by the Science Teachers Association of New York State.

The teachers experts come from states with strikingly different state-level policies regarding science education, with one coming from California where there has been extensive work on statewide science objectives and curriculum frameworks. Another teaches in New York where statewide testing in science is emphasized and curriculum is organized around a state syllabus. The other comes from Delaware where state-level policies leave more decisions to individual districts.

It is interesting that all of the experts have been involved in curriculum development work at some level. Two university experts have done curriculum development work within the context of their research on teaching and learning. The third university expert is currently developing, publishing, and implementing a K-6 science series. Because of this curriculum development work, all three university-based experts had been challenged in their work to take theoretical, research-based ideas and to explore the ways in which such insights could impact on classroom practice. Thus, all three experts had dealt with the realities of classroom teaching and learning at the elementary or middle school level.

The teachers also were involved in curriculum development work in different ways. T2 led his district in defining science objectives and curricula for science. He led teacher workshops in which teams of teachers worked under his supervision to create units of instruction. T1 developed a model conceptual change unit on light and shadows which he has taught and revised several times now. T3 field-tested and evaluated curriculum units about plants developed by local university experts. She also received a minigrant to do summer curriculum work in developing two physical science units for K-2, emphasizing conceptual development as a central component of these units.

Data Collection Procedures

Data were developed from two sources, identified to the experts as Part I and Part II of the study. Part I was a detailed, written response to a set of questions asking the experts to identify key features of ideal science curricula and then apply these ideas by indicating how they would organize instruction relating to each of three broad science goals (teaching about interactions of living things and their physical environment, teaching about cyclic, sequential, and evolutionary change, and helping students develop a disposition to inquire and make sense) at each of two grade levels (second and fifth). The experts were asked to identify key understandings relating to each of these goals, indicate how those understandings are related, and tell how they would organize the understandings for presentation to students. Then, they were to select one of the key understandings for each goal and indicate how they would teach it at the second- and fifth-grade levels, noting the information that they would provide to students, the nature of the teacher-student discourse that would occur, the activities or assignments that would be included, and the methods that they might use to evaluate student learning.

Instructions for Part I (see Appendix A) were sent to the panelists by mail. The panelists then prepared written responses to Part I and mailed copies of these to us upon completion. Upon receipt of these written responses to Part I, we sent the panelists the instructions for Part II along with the curriculum materials to be evaluated (the Grade 1-6 teachers' editions of the 1989 Silver Burdett & Ginn [SBG] Science series, Mallinson, Mallinson, Valentino, & Smallwood), which include not only the student text but the worksheets and other supplements supplied by the publisher and the instructions to the teacher concerning recommended instructional methods and follow-up activities.

For Part II, the panelists were instructed to review and critique the SBG curriculum using a provided set of framing questions (see Appendix B). Instead of writing final form responses to these framing questions, however, the panelists were asked to develop detailed notes about them that would be elaborated during extensive interviews to be conducted at Michigan State University. Once the panelists had completed the instructions for Part II of the work to be done at home, they were brought to Michigan State University for lengthy (approximately 6-hour) interviews conducted by the authors. During these interviews, they elaborated on and responded to questions about their written responses to Part I that had been sent in previously and then they led us through their notes on the SBG curriculum series, elaborating, showing examples, and answering questions as they proceeded. Copies of the curriculum were kept handy for reference to examples.

Completion of these interviews ended the panelists' formal involvement with the study, although they were later provided with copies of their interview transcripts for their own use. The panelists were reimbursed for all of the expenses incurred in coming to Michigan State University to be interviewed and

they also received a modest honorarium in partial compensation for their time spent preparing written responses to Part I and notes for Part II of our framing questions.

Data Preparation and Analysis

The panelists' written responses were typed (if handwritten), and audiotapes of their interviews were transcribed and corrected. To protect the panelists' anonymity, the materials were assigned code numbers, and names, institutional affiliations, and other personal references were removed. We analyzed the data in two stages. First, we sought to develop a clear and shared understanding of what each panelist had said. Toward this end, we each independently read all of the material available on each panelist (the submitted written materials plus the transcript of the interview); took detailed notes; and prepared summaries of the views expressed concerning the purposes and goals of science education and the features of ideal curriculum, instruction, and evaluation practices in elementary level science. We then exchanged and studied these summaries, seeking to identify areas of disagreement that called for discussion and resolution. Discussion continued until we were satisfied that we had developed shared understandings about the key elements in each panelist's positions and about how these compared and contrasted with those advocated by the other panelists. The conclusions developed during this first phase of data analysis are presented in the first part of the results section to follow.

The second phase of data analysis involved systematic comparison and contrast of the views among the panelists. For this second phase of analysis, both the raw materials and the conclusions developed in the first phase of analysis were searched for common dimensions that apply to all or at least most of the panelists' responses and thus could be used as a basis for comparing and

contrasting the responses. Proposed common dimensions and statements of similarity or difference were then circulated among the authors for critique, elaboration, or qualification; and once again this process was continued until consensus was reached. The conclusions we reached about similarities and differences are given in the discussion section. These analyses are primarily qualitative; because of the small numbers of panelists involved, no attempt was made to conduct formal statistical analyses.

The University-Based Experts

There were not striking differences among the university experts in terms of the content they would emphasize in elementary science. The experts pointed to similar key concepts to be emphasized, and they often used the same words to characterize their views of science teaching and learning (inquiry, conceptual change, constructivist). However, their images of how these words might be translated into real classroom curricular and instruction differed. In addition, the experts differed in terms of the extent to which they advocated a particular model of instruction versus a more eclectic, multipronged approach. We begin with the expert who had the most model-bound view.

P1: Summary of Approach

Background and Overall Perspective

P1 brings a conceptual change perspective to this curriculum analysis. Over the last 10 years he has been actively involved in classroom research investigating science teaching and learning. This research (much of which has investigated teaching and learning in fifth- and sixth-grade classrooms) has investigated science teaching and learning in classrooms from a cognitive science perspective. This body of research on students' ways of understanding and making sense of science instruction helped P1 articulate what it takes for students to "understand" science. The research has also demonstrated that

what most students are learning in science classes could not be termed "understanding" by any reasonable observer.

P1's interests have focused on the personal concepts and strategies (variously labeled misconceptions, alternative frameworks, naive conceptions, personal theories, etc.) that students bring with them to science classrooms. Even before they begin formal science instruction, students develop informal, useful and integrated concepts and strategies that they use to make sense of the world around them. Their ways of "understanding" are often substantially different from those taught in science classes, but they are personally sensible and quite resistant to change because they are based on the student's own thinking and experience. Achieving conceptual integration between students' personal knowledge and formal scientific concepts is a complex, difficult process of conceptual change. P1's work has documented that this process of conceptual change occurs rarely for most students and that science instruction (whether didactic and textbook-based or inquiry and activity-based) does not support students in this process. Instead, students memorize enough facts and algorithms to pass tests without substantially altering their own personal concepts and learning strategies. Existing patterns of science teaching practice enable students to get by or even do well without really understanding critical science concepts.

In his research, P1 has explored the curricular and instructional implications of a conceptual change view of learning. With his colleagues, he has developed curricular materials and teachers' guides for selected units that promote a conceptual change orientation to science teaching. He has studied the usefulness of such materials in enabling teachers to promote conceptual change learning. Successes in individual classrooms enabled P1 to identify key features of effective conceptual change teaching and to articulate and

gradually refine a conceptual change model of instruction. P1 has also explored strategies for helping teachers (both inservice and preservice) adapt existing curriculum materials in ways that will better promote conceptual change learning.

In his current work, P1 and a colleague are extending the conceptual change teaching model a step further. They argue that the ultimate goal of science education is to prepare citizens for using scientific knowledge and a variety of resources to solve complex, messy real-world problems. P1 suggests that a conceptual change model needs a new component that includes explicit instruction in self-regulation of problem-solving strategies.

Goals of the Ideal Science Curriculum

P1 defines two explicit and critical goals of the science curriculum: To help students understand important scientific concepts and principles and to help students develop strategies for self-regulated problem solving. Both of these goals must be achieved to enable scientific literacy in real-world, out-of-classroom situations. The use of scientific knowledge in solving complex, ambiguous, real-world problems is the ultimate goal of K-12 science education. Thus, P1 does not approach curriculum goals by defining particular content knowledge that all students should understand by the time they finish elementary or high school (an approach taken by the American Association for the Advancement of Science Project 2061, AAAS, 1989). Nor does he view it useful to emphasize science process skills as the primary goal of science education (an approach taken by many curriculum developers of the National Science Foundation-sponsored projects of the 1960s and early 1970s). Instead, he advocates the development of deep understanding of a limited number of scientifically important concepts as the heart of the science curriculum. Such

understandings provide an essential base for development of more complex problem solving and self-monitoring strategies.

The nature of scientific understanding. P1 has a clear vision of the nature of scientific understanding that he would like to see elementary students develop. Two broad aspects of students' scientific cognition are of particular interest to him. The first of these he terms conceptual integration. People understand a scientific principle or theory to the extent that they have integrated an accurate formulation of that principle into their own personal conceptual ecologies (see Posner, Strike, Hewson, & Gertzog, 1982). P1 describes this aspect of scientific understanding as the structure of knowledge. Students, like scientists, will have more meaningful understandings when they can integrate scientific explanations with their own experiences, observations, and prior knowledge. Students need to connect ideas and concepts and see how those concepts can be related to each other in a variety of ways. Thus, understanding is not fragmented knowledge of bits of information.

A second aspect of scientific understanding is the usefulness, or functions, of scientific knowledge. People are considered to understand a scientific principle if they can use it to make sense of the world around them. "Making sense of the world" is defined in terms of four important functions that scientific knowledge serves for our society and for scientifically literate individuals (see Anderson & Roth, 1990). These are description, explanation, prediction, and control of real-world objects, systems, or phenomena. Students' failure to understand is often not apparent on the tasks included in typical science tests, which can often be completed successfully on the basis of memorized word associations or algorithms for manipulating numbers and symbols. The difficulty is more apparent when they engage in more complex

and realistic tasks such as those in which they must describe, explain, make predictions about, or control the world around them. In these situations, students often find that their memorized scientific knowledge is useless, and they rely instead on their comfortable and familiar alternative frameworks.

Self-regulated problem solving. P1 argues that conceptual understanding alone is not enough to enable students to solve the kinds of problems they will face in out-of-school contexts. He describes four ways in which the situations in which people use scientific knowledge outside of classroom settings are generally complex and ambiguous:

> -First, the tasks themselves are often inherently complex, involving coordination of multiple pieces of information or extensive cognitive processing.
> -Second, it often is not clear what information or knowledge is relevant to their solution, or whether the problem solvers possess all the information and knowledge that they need.
> -Third, problem solvers in out-of-school situations often have access to a variety of tools or sources of information and advice that they can choose to use or not to use.
> -Finally, problem solving in out-of-classroom situations is often social rather than individual in nature, involving a variety of people playing different roles. (Written document #2, p. 4)

Understanding scientific concepts and principles is necessary for solving such complex problems, but it is not sufficient. The individual or group also must be able to make decisions about which concepts are applicable and what knowledge is needed to derive an appropriate solution. Problem solvers then must have strategies for obtaining the needed information and using it to solve the problem. P1 describe features of self-regulation that are needed in such problem-solving contexts: (a) evaluation of the compatibility between prior concepts and new information that is encountered, (b) decisions about whether the strategy being pursued will lead to an appropriate solution, and (c) determination of when an appropriate solution has been achieved. These are the self-regulation features of problem solving that P1 advocates as explicit goals

of the science curriculum. Students need to be taught how to use conceptual knowledge to solve problems and to monitor their own problem-solving strategies:

> Kids are not going to learn to engage in self-regulation in solving complex problems unless they in fact have some complex problems to solve. Therefore, to do this you would need to shift toward a task environment where kids have relatively more . . . messy, ambiguous, complex problems to deal with and an explicit goal of instruction is to help them figure out how to work through that set of ambiguities and messiness. (Tape 1, p. 10; emphasis added)

Embedded, or hidden, goals of the ideal curriculum. P1 defines conceptual understanding and self-regulated problem solving as the two major, explicit science curriculum goals. However, he also believes that there are other important goals of the science curriculum that he labels as part of the hidden curriculum: The development of positive attitudes toward science and an understanding of the nature of science and social norms in a scientific community. In using the hidden curriculum descriptor, P1 is suggesting that these goals are difficult (if not impossible) to assess and measure formally.

In addition, he suggests that it does not make sense to focus instruction on these goals as separate pieces of the science curriculum. Instead, these goals are embedded in a curriculum that focuses on conceptual understanding and self-regulated problem solving. If the students develop meaningful conceptual understandings and learn to solve problems, positive attitudes and understandings of the nature of science and social norms in a scientific community will be achieved during that process. Thus, P1 assumes that these goals do not need to be explicitly taught or considered in the curriculum; they will be natural outgrowths of a conceptually focused, meaning-centered science curriculum.

Attitudes about science. P1 agrees that students should develop an understanding of the nature of scientific inquiry and an appreciation of science and its place in society. He suggests that the curriculum could have an explicit

emphasis on helping students understand scientists' work and the history of science. However, he is concerned that explicit instruction of such goals will tend to move toward explicit teaching of "the" scientific method. This is problematic because explicit teaching of this method paints a rather simplistic view of science as an extremely orderly, carefully sequenced set of steps and procedures that will lead to new knowledge. Presentations of the scientific method make the process look much neater than it really is, and they also deemphasize the role that scientists' existing knowledge structures play in the construction of new knowledge. P1 believes that students will learn more about the nature of science by being engaged in solving meaningful scientific problems. In the process of using a variety of strategies (including formal controlled experimentation as well as other strategies) and receiving careful modeling and coaching from teachers about appropriate kinds of evidence to use in coming up with explanations and solutions, students are likely to internalize a much richer view of science than they would from formal lessons about the nature of science.

Social norms in a scientific community. P1 has defined four key characteristics of classrooms that support students in developing conceptual understanding and complex problem solving strategies. These four characteristics enable the creation of "a culture of expert practice in the classroom." They are characteristics of the scientific community that he would like to see as part of the science classroom culture:

1. Intrinsic motivation. Students are personally interested in learning and solving problems. Students realize that they value wanting to be able to understand and to solve problems.
2. Public sharing of thinking processes. Students must be willing to share their ideas with others. This involves risking that one's own thoughts may be different from classmates. In addition to risking embarrassment by revealing one's own thoughts, each student must be willing to listen seriously to the ideas of others. Taking each others' ideas seriously does not mean accepting all ideas uncritically; rather, each student has the responsibility

to criticize others' ideas with the goal of helping each other try to work toward better thinking and understanding.

3. Settling of disputes through reason and mutual understanding. Students must have other ways of settling disagreements besides appeals to authority or by name-calling. Equally unproductive is an unwarranted relativism, in which arguments go unchallenged because "everyone has a right to their own ideas." Differences are resolved instead through appeals to evidence or reasoned authority-warranted arguments.

4. Encouraging public revision of ideas. In this culture, public revision of ideas should be viewed as a sign of successful learning rather than a sign of previous stupidity (Written document #2).

P1 views these as social norms in a science classroom rather than as explicit curriculum goals:

> You have to establish in the classroom a set of social norms with which . . . these kinds of behavior are expected and accepted as normal. Over the long term hopefully these kinds of behavior will be internalized by the students but I don't know as that's necessary . . . you can put those up as curricular goals but more than the curricular goals I think it needs to be characteristic of the environment within which the students work. . . . The primary goal is not internalization; the primary goal is just having this be the way kids act in the classroom and trusting that internalization will occur." (Tape 1, p. 11)

P1 argues that it would not be productive to try to develop test questions that assess the degree to which students have acquired these attitudes, beliefs, or skills. Instead, we should be assessing for the conceptual understanding and problem-solving outcomes and leaving the attitude outcomes as part of the untested, hidden curriculum. "And of course, the fact that something is in the hidden rather than in the explicit curriculum does not mean that it is any less powerful as a form of learning" (Tape 1, p. 12).

Higher Level Thinking in the Ideal Curriculum

P1 takes issue with the use of the term, "higher order thinking skills." Instead, he uses the terms "conceptual understanding" and "self-regulated problem solving" to describe the kinds of complex thinking that scientists and scientifically literate citizens do. Rather than a hierarchy of increasingly sophisticated kinds of thinking that "higher order" suggests, P1 views

scientific understanding as an integrated web of knowledge that can be used meaningfully in a variety of ways. He describes how very young children can do quite complex forms of thinking; therefore, he critiques descriptions of thinking that suggest that complex forms of thinking lie on a developmental continuum. He disagrees with the notion that learners must have "the basics" or simple skills before they can develop more complex thinking skills. Instead, P1 talks about "basic understanding" (Tape 1, p. 2) as requiring many kinds of higher level thinking. It is not productive, however, to isolate these kinds of thinking skills and teach them one by one. Rather, students will learn to value and pursue these kinds of thinking as they see the rewards that come with really understanding something. The important thing is to engage students in the kinds of thinking that will lead to understanding; it is counterproductive to label different kinds of thinking skills and then try to teach them explicitly.

It is clear, however, that P1 does view some kinds of thinking as more complex and challenging than others. For example, he distinguishes between the way that lower elementary students and upper elementary students will be able to use scientific knowledge. P1 emphasizes that lower elementary students are ready to use scientific knowledge primarily to describe and classify their world. Older students are more ready to use science concepts to make predictions and explanations about natural phenomena.

P1 also views conceptual understanding as a necessary prerequisite for more complex problem solving. In describing his sample lessons and his view of the overall K-5 science curriculum, he reflects a view of student progression of "understanding." First students will develop conceptual understandings that they can use and apply in fairly controlled and structured problem situations. Once solid conceptual understandings are in place, students can begin to work

on the development of more sophisticated thinking--problem-solving strategies and self-regulation goals. This suggests that self-regulated problem solving is a "higher" or more complex kind of thinking than conceptual understanding.

Alternatively, P1 may be envisioning conceptual understanding as a continuum. Basic understanding is evidenced when students can apply concepts in limited, fairly controlled contexts. More complex, deeper understanding is suggested by the learner's ability to use new knowledge in more complex, "messy" problem-solving situations. Certainly, however, P1 views self-regulated thinking or problem-solving as a more complex kind of thinking than conceptual understanding. He does not see this complex kind of thinking as linked to developmental stages, however. He emphatically asserts that even the youngest school children can be developing self-regulated problem solving skills.

Societal issues. P1 also views thinking about science and societal issues as a complex form of thinking. He is skeptical that elementary students can learn to think very productively about many science and societal issues because of that complexity. Here P1 is not defining this kind of thinking as "higher" level; rather, it is simply more complex because it requires a person to weave together social, political, technical, and scientific concepts and issues. In his sample ecosystem lesson plans, for example, he did not build in goals concerning pollution and conservation. In defending that decision, he described the dangers of teaching people simply to learn rules from their science education:

> This is good and this is bad and this is the way you're supposed to live your life. I think teachers find those kinds of things easy to teach and kids find it easy to understand, and they're somewhat in variance with my idea of what science consists of. (Tape 132, p. 11)

P1 is reluctant, however, to reserve all consideration of these kinds of issues for secondary school students:

> They're certainly not to be avoided completely. No, I'd say when it is possible to deal with them, you ought to deal with them. . . . But you ought to deal with them in situations where you can argue from evidence rather than from authority. Maybe that's the key factor here. An awful lot of times what is actually happening is that the authority of science is being invoked in favor of some political position and I think ultimately that is a very dangerous thing to do for the authority of science. (Tape 132, p. 12)

Thus, P1 views this kind of thinking as difficult for elementary students to do in meaningful ways.

The K-6 Curriculum: Content Selection and Organization

Criteria for content selection. In P1's view, the two primary criteria for content selection should be conceptual integration and usefulness of the knowledge. Content needs to be selected that can connect with children's experiences and thinking. This suggests that one has to think seriously about what children know and experience and about what children are capable of understanding. But P1 argues that you also have to think carefully about what is important and useful knowledge for students to learn about in science. Using this criterion, there must be a disciplined-based judgment about the importance of the knowledge.

It must not only be clearly useful to students in their experiences in the here and now, but also serve as an important step on a long-term path of development. Thus the understandings that students are developing should provide a base for future learning. In his own ecosystem sample unit planning, P1 described how he worked back and forth among these different criteria with no single criterion driving his selection of which content to include. He considered what he knew about students and their ways of thinking about ecosystems as well discipline-based views of important ecological concepts. He also thought

about ways this knowledge could be seen as useful to elementary students by considering different kinds of problems that they might be able to solve.

P1 asserts that there is a great deal of science content that could be included in the elementary curriculum that meet his criteria of integration and usefulness. Since it is impossible to come even close to including all of this content, P1 believes that the choice among them is somewhat arbitrary. P1 believes that it is reasonable to consider teacher interest and teacher knowledge as important factors in curriculum decision making. "We have to devise methods of teaching that do not assume really deep expertise in content on the part of the teachers." He worries about curricular recommendations such as Magdalene Lampert's in mathematics (Lampert, 1990) that encourage teachers to explore the subject matter in a kind of cross-country approach, investigating subject matter primarily in response to student ideas and following the path of inquiry wherever it takes you.

On the one hand, P1 argues that we need to prepare teachers with better subject matter preparation in science. On the other hand, he suggests that we should be realistic in our expectations of elementary teachers' knowledge of science. He also acknowledges that a focus on collaborative group problem solving using more complex problems puts additional demands on teachers' knowledge. In selecting problems to put in the curriculum, P1 would seriously consider teacher knowledge and experience as well as availability and cost of materials.

Content integration within and across grade levels. Although P1 is in favor of integrated curriculum both within and across grade levels, he seems skeptical that this is feasible in the real world of schools where children move from one school to another. He advocates something like a spiral curriculum in which ideas about subjects such as energy or ecosystems or

populations are explored in increasingly deep and complex ways across the K-6 span. However, in practical terms he suggests that it is not worth a great deal of time and effort to think about a K-5 scope and sequence since such sequences are rarely enacted in meaningful ways. Instead, he would be satisfied if each grade level teacher taught students some well-integrated and useful scientific concepts--the content or concepts covered at the preceding grade levels is not of utmost importance. The important thing is that students develop meaningful understandings of whatever it is that they study in science.

Depth vs. breadth. P1 is clearly an advocate of depth over breadth. He advocates exploring concepts long enough and in enough different contexts so that students can develop good understandings. He is particularly critical of fact- and vocabulary-laden curricula. Better to teach students how to use a few concepts and facts in meaningful ways than to "cover" lots of content. In making this point, P1 points to his college students who, after having studied biology in junior high, high school, and college give answers to questions about basic biological phenomena that are not significantly different from those answers given by fifth graders (Anderson, Sheldon, & DuBay, 1990). Clearly, all those terms they memorized in covering the waterfront of biology did not promote meaningful learning. What is the point of reteaching the same terms on each pass through biology? Why not help them really explore and understand some concepts so that something will stick with them?

Views of Science Teaching and Learning

P1 has a well-defined view of the kinds of teaching that are needed to help students develop conceptual understanding and self-regulated problem-solving strategies. His instructional model is based on research (of his own and others) that has revealed the thinking processes of students in science

classrooms and the complexity of conceptual change learning. P1 has identified at least four elements of a teaching approach that promotes understanding and problem solving: (a) conceptual change teaching, (b) appropriate social norms and task environment, (c) strategy instruction, and (d) collaborative group problem solving. Embedded in each of these elements of P1's instructional model is what Collins, Brown, and Newman (1986) describe as a "cognitive apprenticeship" approach to science teaching, in which the teacher's role shifts to that of cognitive coach and the student's role is an active one of constructing knowledge under the coach's supervision. P1 has described these four components in detail in the written documents he submitted. We will briefly summarize his ideas, drawing from P1's written description in the submitted documents.

Conceptual change teaching. Table 1 summarizes the key elements of P1's vision of a conceptual change instructional model: (a) establishing a problem, (b) modeling of scientific description, explanation, prediction, control, (c) coaching students as they work on tasks, (d) fading support until students are capable of independent application, and (e) maintenance by building bridges between one unit and another. P1 elaborated this model in one of the written documents submitted:

Establishing a problem. In this model instruction begins with the establishment of a problem. Teachers ask students questions that elicit their reasoning about the topics they will be studying and listen to what students say. This process activates prior student knowledge, helps make them aware of its limitations, serves an important diagnostic function for the teacher, and engages teacher and students in dialogue about commonly understood issues. The problems that work best for this purpose tend to focus on explanations and predictions about objects and phenomena that are familiar to the students: How

do plants get their food? Why can you see things better in the daytime than at night? Why do you have to breathe all the time? This process helps students realize that their study of science is related to things they already know about the world. The problem is one that students revisit frequently throughout a unit of study, keeping track of ways in which their ideas about the problem are changing in response to evidence and argument.

Modeling. If appropriate problems are established at the beginning of a unit, students will see that although they have important knowledge and beliefs about the problem, they cannot solve it adequately without additional knowledge. At this point the teacher and students enter into scaffolded dialogue, in which students encounter and use new scientific ideas. The students should encounter new ideas in contexts where both the usefulness of those ideas and the relation of those ideas to their own personal knowledge are apparent to them. This implies that modeling, in which the teacher shows how scientific knowledge can be used to solve a problem, is a more appropriate way to present new ideas than traditional lecturing. It also implies that teachers should be very specific about how scientific ideas connect or conflict with ideas that the students have expressed.

Coaching. No matter how well scientific concepts are presented, students cannot understand them in meaningful ways without using the ideas themselves to describe, explain, predict, or control the world around them. P1 believes students need extensive support in their initial attempts to use new ideas. This support can come through careful scaffolding of tasks and in classroom dialogue in which students listen carefully to each other and respond to each other in ways that reflect respectful attention to the ideas of the speaker. Such dialogues provide a context in which teachers can coach students or students can coach each other as they use new ideas.

Table 1

P1's Instructional Model

Teaching Strategies for Conceptual Change

A. Establishing a problem.
   1. Using familiar situations and discrepant events.
   2. Eliciting students' descriptions.
   3. Encouraging discussion and debate amount students.

B. Modeling of scientific description, explanation, prediction, control.
   1. Presenting scientific information in the context of real-world problems.
   2. Explicit contrast between misconceptions and goal conceptions.
   3. Emphasizing main points.
   4. Thinking aloud.

C. Coaching students as they work on tasks themselves. This includes:
   1. Scaffolding.
   2. Feedback and reinforcement.
   3. Cooperative group work by students.
   4. Using textbooks and other resources.
   5. Repeated practice and application.

D. Fading support until students are capable of independent application (e.g. tests and other means of evaluation).

E. Maintenance: "Building bridges" between one unit and another.

(from Written document #4, p. 1)

Fading support and independent use of ideas. If students are to use scientific knowledge outside the classroom context, the support must be gradually faded out until students are able to construct explanations and predictions independently. Thus, students need numerous opportunities to apply new concepts to real-world situations.

Appropriate task environment and social norms. P1 argues that the conceptual change teaching strategy described above can help students develop well-integrated and useful conceptual knowledge but still fall short of enabling students to develop self-regulation in complex learning/problem-solving situations. Thus, he advocates the inclusion of tasks that are complex, ambiguous, and tied to real-world settings. Engaging students in such complex tasks requires the maintenance of social norms that allow students to risk failure, to evaluate their own success and that of others honestly, and to take others' ideas seriously without accepting them uncritically. Key characteristics of classrooms that support such student engagement include intrinsic motivation, public sharing of thinking processes, settling of disputes through reason and mutual understanding, and encouraging public revision of ideas. Because these norms are not typically predominant in elementary school classrooms, P1 believes they must be consciously developed and maintained through modeling and coaching, feedback and reinforcement, and explicit discussions of the nature of appropriate behavior.

Strategy instruction. Drawing from research on self-regulated learning (Palincsar & Brown, 1984; Schoenfeld, 1985), P1 argues that it is possible to help students master complex self-regulatory strategies through instructional programs that have the basic characteristics of cognitive apprenticeship and guided practice in monitoring of problem solving activity. Such strategy instruction needs to be built on research describing more and less successful

learning and problem-solving patterns in science. P1's current research is aimed at identifying these patterns in sixth-grade students. His research is focusing on identification of successful and less successful strategies concerning use of tools and intellectual resources, control strategies, beliefs about the nature of science, argument construction, and task definition and term definition in science problem solving. Once such strategies are identified, P1 advocates explicit instruction of the more successful strategies as an important component of science instruction.

Collaborative group problem solving. The final component of P1's suggested approach to teaching for conceptual understanding and self-regulation is collaborative group problem solving, which he identifies as an effective mechanism for increasing the effectiveness of each of the other three components:

> Students' experience working together under appropriate conditions can facilitate the development of constructive social norms. It can also enhance conceptual change teaching and strategy instruction by moving some of the burden of coaching from the teacher to the students, by facilitating the social construction of knowledge, and by making public arguments that would otherwise remain hidden and unexamined. As each student brings his or her prior conceptions to bear in the collaborative problem solving, there will be opportunities for the students to practice the monitoring that is essential to self-regulated learning. In addition, there will be the opportunity to conceptually integrate their prior conceptions with the new information used in problem solution. (Written document #2, p. 9)

P1 does not believe that we have the research knowledge needed to successfully integrate the four components he has described. His current research is focused on extending the research on conceptual change teaching by investigating the other three components of his instructional model. His goal is to collect and analyze descriptive data about sixth graders' cognitive and behavioral characteristics relevant to each component and to develop a program of classroom science teaching that combines all four elements.

Teacher Knowledge, Teacher Change, and Curriculum Development

P1 recognizes that elementary teachers do not typically have the kinds of knowledge needed to teach science in the ways he advocates. His approach to science teaching requires sophisticated and flexible understandings about science concepts, about the nature of science and scientific inquiry, about children's cognition, and about teaching strategies and teacher roles. P1 is interested in investigating ways in which teachers can be supported in developing this knowledge and in teaching for conceptual change. He is not sure that it is realistic to expect all elementary teachers to develop this expertise, but he is exploring ways in which improved curricular materials and more subject matter-focused preservice teacher education can support teacher change.

One of his suggestions for teacher education is that prospective and inservice teachers develop depth of knowledge of a limited number of topics and science concepts, so they will have the flexibility to coach and support students in dealing with a variety of real-world applications. For this reason, he argues that it would be a mistake to let students dictate the curricular territory to be covered in science. The teachers are unlikely to have the depth and breadth of knowledge that would be needed to support student learning in any potential area of student interest. Thus, P1 is supportive of teacher selection of topics and concepts to be covered.

P1's major criticisms of the Silver Burdett & Ginn text series focus on its failure to support teachers. The text does not support teachers in modeling, coaching, and scaffolding students' efforts to develop explanations:

> If you look at the activities and worksheets, there are a lot of pretty good things for kids to do, but there's no help for the teachers to help them [students] get better. There's very little scaffolding to help the kids . . . very little modeling, coaching, fading, and very little push toward using scientific knowledge to

> do the activities as opposed to relying on personal knowledge or opinion . . . it's uniformly "repeat what's in the book" kinds of stuff. (Tape 135, p. 5)

P1 views the textbook as a potentially useful tool to support teachers:

> What a textbook needs to do is it needs to help the teacher comprehend, transform, instruct, evaluate, reflect. That's what the teacher needs to do, and the textbook is supposedly a tool which helps the teacher do some or all of those things. So the question you could pose about the textbook is to what extent does it provide support for each one of those activities, and to what extent is that support misleading? (Tape 133, p. 6)

The SBG series fails to provide this support. For example, the text poses some good questions for students to discuss but provides almost no support to the teacher in responding to students' ideas:

> If you do have these more open sorts of questions, you need to have some guidance for the teacher that says "these are the general characteristics of acceptable answers. These are the general characteristics of unacceptable answers and this is what it is that makes the unacceptable answers unacceptable." (Tape 135, p. 6)

> A more serious difficulty is that when you get to these interesting worthwhile questions, what do you get as the suggested answers? Now what the teacher needs at this point is something that says these are the criteria by which you could judge student answers. But instead you get one of two things. You either get "answers will vary," meaning you're on your own. Or you get a single answer proposed as the correct answer to this question where there's a range of possible appropriate answers. . . . Neither of those kinds of responses gives the teacher any help at all in deciding what the range of correct answers consists of and what the criteria for judging and feedback might be. (Tape 133, pp. 14-15)

This critique of the SBG text leads P1 to recommend that textbooks could be improved by providing more ideas for the teacher about possible student responses (both acceptable and unacceptable) and by suggesting ways of responding to students' ideas. In addition, P1 recommends building in more modeling, coaching, and fading into the activities and text questions. He advocates cutting down significantly on the content coverage and vocabulary load to allow more time for students to grapple and work with a few basic concepts.

Thus, P1 believes that curricular materials could better support teachers in elementary science teaching. In his own research, he has used his study of student thinking and learning in science classrooms to develop curriculum materials that feature the characteristics he recommends. His research of these materials in use in classrooms has convinced him that textbooks or curricular guides can be excellent tools in supporting teachers in teaching for conceptual change. However, existing commercial text materials fail to provide such support.

But P1 recognizes the limitations of even the best curriculum materials. He acknowledges that curriculum materials alone are not sufficient to help teachers develop the knowledge they need. Teachers with rich subject matter backgrounds and teachers who have always been sensitive to children's thinking and ideas are able to use his conceptual change-oriented materials more effectively than teachers with limited backgrounds. In addition, text materials alone are not likely to change a teacher's conception of the nature of science and science teaching from a knowledge-telling view to a knowledge-transforming view.

In response to this problem, P1 has been exploring ways of thinking about teacher learning as a process of conceptual change. In an undergraduate teacher education program, he works with colleagues to support teacher learning over a two-year period. In this program students first explore the problem, "What is good science teaching?" Through their studies and field experiences they begin to confront the limitations of what they have defined as "good" teaching. In this context they are introduced to ideas about conceptual change approaches to science instruction. They are provided numerous opportunities across the two-year period to try using ideas about conceptual change teaching in their experiences in the classroom. Course instructors and mentor teachers

work together to model, coach, and scaffold students' efforts to make sense of conceptual change theory and practice. In current efforts to improve this program, P1 is interacting with professors in Michigan State University's College of Natural Science to explore the possibilities of constructing a five-year program for elementary teachers, which might include a content area major in one of the sciences.

P2: Summary of Approach

Background and Overall Perspective

P2 was selected as one of the university-based experts for a number of reasons. First, P2 has been deeply involved in elementary science curriculum work and research on elementary science teaching. She was involved in the development of the K-6 Science Curriculum Improvement Study (SCIS) curriculum materials (Knott, et al., 1978). She has done a large body of research investigating the effects of programs like SCIS on students' developing science process skills. P2 brought to the SCIS development team a strong developmental psychology background and was particularly influenced by the work of Piaget. Because of this experience with process-focused curricula, we thought that P2 might bring a different set of lenses to the curriculum analysis task than P1.

We also expected P2 to bring a different perspective because of her more recent work looking at the role of technological tools in supporting science teaching and learning. In this work P2 has developed a Computers-as-Lab-Partner curriculum unit on heat and temperature. The process she used in developing this middle school unit is an interesting one that has included detailed studies of the unit being taught by the same teacher across several years. These studies have looked very closely at the developing understandings of students in the classroom and the role that the computer activities played in supporting student learning.

Based on this work, we expected P2 to bring both a technology focus and a process-focused orientation to the curriculum analysis that might differ in interesting ways from P1's conceptual change orientation. However, it is difficult to characterize P2's approach as falling neatly into a particular theoretical framework. P2 certainly draws from her developmental psychology background, emphasizing critical pieces from Piagetian and Vygotskian perspectives. She also draws heavily from more recent cognitive science and constructivist views of learning. She is interested in integrating this recent line of work with her earlier work with SCIS and process skills instruction. P2 is interested in technology as a teaching tool and supports technology education but is not strongly committed to a science/technology/society-focused curriculum. In addition, P2 is interested in the research on problem solving and Ann Brown's work on the teaching of self-regulation and metareasoning skills (Brown & Palincsar, 1986). Thus, P2 is attempting to link together a variety of lines of research that she believes could inform elementary science instruction in significant ways.

A particularly interesting aspect of P2's perspective is her acknowledgment of the complexities and dilemmas of integrating these ideas and using them in meaningful ways in elementary classrooms. P2 clearly communicates that she has not yet come up with the answers to these dilemmas. During her interview P2 frequently argued both sides of a position, being unwilling to take a firm position. Thus, we would characterize P2 in some ways as a researcher in transition. Her research has convinced her of the difficulties and complexities of helping students develop connected, useful understandings of science concepts. Because of this work, P2 is unwilling to suggest clear answers to the problems we face in elementary science teaching.

Goals of the Elementary Science Curriculum

P2 supported each of the features of ideal curricula that we suggested: balancing breadth with depth to ensure conceptual understanding, organizing the content around key ideas, emphasizing the relationships among ideas, providing opportunities for students to process and construct meaning actively, and fostering problem solving and other higher order thinking skills in the context of knowledge application. She had a number of other features that she identified as important goals. However, she was reluctant to prioritize these goals or to focus too heavily on such a listing of ideal features. This reluctance stemmed from her appreciation of the realities of implementing these ideas. She preferred to focus her comments on curriculum development processes that would enable these ideas to guide redefinition of the curriculum:

> Although I agree with the key features listed in this document, I prefer to focus on the process of curriculum reformulation rather than on the features characterizing the product. (Written response, p. 3)

> Indeed, it may be that features are not sufficient for determining how science curricula can be improved. It is possible to define the features of an intelligent individual or a good book yet be unable to specify how these features could be achieved. A similar difficulty may arise in defining guidelines for improvement of science curricula. (Written response, p. 1)

One goal that P2 emphasized was not mentioned by the other experts: to encourage people to pursue science-related careers. The importance of this goal led her to an interesting view of the role of activities in elementary science instruction. On the one hand, she favored a "minds-on" approach to science learning and did not view activities per se as the answer to the mindless approach of textbook series like SBG which gave a vocabulary-focused view of science. However, when considering whether the elimination of science from the elementary curriculum would make sense, P2 shifted her position about

mindless activities. She explained that doing fun but mindless activities would be a better choice than using a vocabulary approach to science or having no science at all. Her main concern here was about the lack of a pool of scientifically interested people:

> So, if it's a choice, I'm going to go with the activity no matter how unrelated it is to anything, because you know a lot bigger problem than whether we teach things in science is whether anyone persists in the area. . . . I think that perhaps one of the big drawbacks to things like Silver Burdett and other programs that are available is that when they are used, they do turn kids off to science. . . . You can't imagine the certainty you could have in these units. I mean all you have to do is memorize the vocabulary and you're going to do okay. I mean that's great, that's wonderful, if that were science! I think that we'd attract a completely different group of students from the ones we need. (Tape 123, p. 10)

Another important goal that P2 added to our list was a focus on thinking skills, including reasoning skills, science process skills, problem-solving skills and self-monitoring and metareasoning skills. At times P2 talked about these skills as a separate component of the curriculum from content-related goals: "It seems to me that whatever you want people to learn in science . . . it's going to have a component that has to do with the content of the domain and a component that has to do with something like reasoning or problem solving." Consistent with this view, P2 suggested times when process skills could take the lead as a curriculum goal (with content goals as secondary goals). For example, students could be taught about histograms and different ways of displaying and interpreting data. She argued that teaching students to comprehend various data displays could enable them to develop powerful understandings of a variety of scientific concepts, and the development of this science process skill could later serve the development of conceptual understanding.

However, P2 at other times suggested a closer relationship between thinking skills and conceptual knowledge. On these occasions she described process

skills as being developed within the context of studying particular subject matter content. For example, she discussed her research on students' abilities to control variables and design controlled experiments. P2 noted that it is more difficult to help students understand the particular variables (about heat and temperature, for example) than it is to help them understand the importance of controlling variables. As she explains, students quickly appreciate that you don't start a foot race with half the group ahead of the other half. However, "a lot of the history of science is composed of people failing to control variables that they didn't realize were important." Thus, students need to learn a lot about the particular variables in their heat and temperature work before they will learn how to control variables in this domain.

P2 was an enthusiastic supporter of the use of new technological tools, such as the computer, as instructional vehicles. However, she was less certain that teaching <u>about</u> technology should be an important goal of elementary science instruction.

> I don't know that it <u>needs</u> to be in the curriculum. I think that the curriculum could be real exciting with technology. I think that we sort of have an obligation to think about how technology fits into school just like we've been thinking about how technology fits into all other aspects of our lives. . . . The goals of science will change because of some the opportunities that technology provides and we will change the nature of the technological tools as we get better understanding of what we want technology to help with. (Tape 2, p. 12)

The focus of P2's discussion of technology in the curriculum was on the role of technology as a teaching tool; she did not recommend a strong focus on science, technology, and societal issues as the content of elementary science instruction. She suggested that technological understandings would grow out of students' meaningful use of technological tools.

P2 talked frequently about integration as an important goal for elementary science instruction. She distinguished "real integration" from the types of

integration activities suggested in the SBG series. These activities she viewed as primarily token efforts to integrate science with other subject areas:

> These books . . . they do have what do you do in math, what do you do in social studies, what do you do in art, what do you do in music, for each of their little, tiny topics. But leaps are just astounding! You know, now that we've done this, let's learn this poem. Oh we've done this, here's a song to sing. Oh, we've done this now let's go into math and we can learn all the metric system. Sometimes the leaps are actually a greater piece of information to learn than what they studied in science. It would be daunting to anybody to try to actually provide the linkage between those pieces of information. (Tape 123, p. 7)

Like other experts, P2 mentioned students' conceptual change as a goal. She talked about the difficulties of helping students change their misconceptions and see alternative perspectives as believable. She contrasted this goal sharply with the vocabulary teaching goal in the SBG series.

Higher Level Thinking in the Ideal Curriculum

P2 had a variety of ways of describing facets of higher level thinking in elementary science. She discussed the importance of developing problem-solving thinking skills and self-monitoring kinds of thinking among elementary students. She also considered various science process skills to be part of higher level thinking in science (controlling variables, making inferences). However, her emphasis, like that of our other experts, was on coherent, integrated understandings of complex subject matter. Her experiences with the heat and temperature unit clearly influenced her formulation of what it means to understand something deeply. She appreciated the difficulties involved in helping 11- to 13-year-olds understand just a few major concepts related to heat and temperature:

> We only had one concept when we were doing it in 10 to 14 weeks, and we found that it was very hard to get across. . . . I think that we were actually astounded too when we did our thermal

> dynamics instruction to discover just how difficult it was for us to actually teach a difficult concept. (Tape 123, p. 8)

P2 pointed out the difficulties of defining an acceptable level of understanding for students. She emphasized the importance of thinking about levels, or plateaus, of understanding. She put understandings that linked ideas across subject matter disciplines as at a higher level than understandings about one topic within the discipline. She wavered on the extent to which such cross-disciplinary connections were reasonable goals in the elementary science curriculum, however. On the one hand, she was intrigued by an English primary school teacher who pursued a yearlong curriculum focused around skeletons. In this study, students delved into physiology, X-rays, comparative anatomy, classification, and so forth in science; studied anthropology and archeology in social science; and pursued proportional reasoning in mathematics to measure skeletons. On the other hand, P2 advocated the use of science specialists in elementary schools. Such specialists could provide integration within science across grade levels, but the opportunities for cross-disciplinary understandings would be lessened. P2 leaned toward abandoning the cross-disciplinary goals in favor of within-science integration and depth.

The K-6 Curriculum: Content Selection and Organization

Criteria for selection.

> I'm reluctant to make a list or set of criteria. I think that's how all these books [SBG and others] got created, and actually I suspect that anything that I put on my list of criteria, they could show me was in those books. Everything's in those books. (Tape 123, p. 11)

Despite this disclaimer, P2 did have a number of criteria that she thought were important to consider in selecting and organizing content. She began by describing the process by which she thought content should be selected and organized:

> Ultimately to improve elementary science curricula, we need multidisciplinary teams of experts including those familiar with classroom practice, those who understand students, those who have developed theories and principles of instruction, those who understand the subject matter, those who understand how technology might be used effectively, those who are familiar with the economic situation of schools and understand how resources might be commandeered, and those concerned with preservice and inservice teacher education. I represent but one component of this multidisciplinary team. My contribution is to examine how principles from research on learning and instruction can be used to guide curriculum design. (Written response, p. 2)

Thus, P2 emphasizes a collaborative approach to curriculum design, along the lines of the development the SCIS curriculum.

What criteria would P2 suggest this panel of experts consider? The first criterion she mentioned was to pick content that elementary teachers understand. She suggested this criterion for two reasons. First, she explained,

> I think it is worth asking that if an elementary school teacher does not understand the scientific concept, why do their students need to understand it? I mean they've lived their lives, gotten a job, and raised families successfully without this information. Maybe it doesn't need to be in the elementary curriculum. (Tape 123, p. 5)

Another reason to justify this criterion is the complexity of teacher subject matter knowledge needed to teach for understanding and higher level thinking:

> Much research on effective curriculum materials demonstrates that instructors who can model their own problem-solving process for students, who can demonstrate the kinds of choices that they make in coming to understand the subject matter, and who can guide students to engage in these same thought processes, are the most effective. Such teaching strategies are only possible if the subject matter is well understood by the instructor. To insure that the instructor has an integrated understanding of the subject, a personalized curriculum seems appropriate. (Written response, pp. 7-8)

By a personalized curriculum, P2 means tailoring the particular subject matter being taught to particular teachers' strengths and interests. In this vision of elementary science, each teacher in the third grade in a given school district might teach very different subject matter. By adapting the curriculum

to the teachers' interests and areas of expertise, it is more likely that teachers will have the "extremely robust and integrated understanding of their subject matter" (Tape 123, p. 15) that is needed to impart understanding to their students. P2 uses the example that she would not argue with a teacher who loves photosynthesis who wants to teach photosynthesis to fourth graders. Although P2 asserts that this concept does not fit her "concrete" criterion (see below), she would encourage the teacher to teach it. "It's more important for your students to see that you're enthusiastic and that you understand it than almost anything I can think of" (Tape 123, p. 9).

In addition to content interesting teachers, it should also be interesting to students. P2 does not elaborate in the interview how she would assess student interest and its relative importance as a content selection criterion. However, she does link student interest to another important criterion: The degree to which the content is related to students' experiences and naturally occurring problems. Heat and temperature and reproduction meet this criterion because students encounter them in their everyday lives. However, photosynthesis does not meet this criterion even though it is a very important issue in biology. It also does not meet another of her criteria: Content that it is possible for children to understand in meaningful, connected ways. Photosynthesis, she asserts, is "a hidden process, it's extraordinarily complicated, it isn't fully understood by scientists. . . . It's really bound up in a lot of stuff that's really, really hard for anyone to understand" (Tape 123, p. 9).

P2's discussion of whether density should be included in the elementary curriculum is one of those occasions when P2 argues with herself as she talks. She begins by picking out density as a concept that is very important for elementary students to learn about. But as she talks through this possibility

she winds up with a very different position about whether density should be in the elementary curriculum:

> There are some concepts like density that are real important. . . . One that you'd kind of like kids to have understood, but I don't think that you'd be real confident in having taught density so that nobody learned it. I'd rather you didn't teach it if you're going to end up with your students thinking that if they give you a displacement task, the weight of the object is more important than its size in determining how much liquid has been displaced. So there's no sense in reinforcing that notion, so I wouldn't encourage having it taught unless I was reasonably certain that some understanding would follow. (Tape 123, p. 12)

Here P2 goes back to her criterion about teachers (teachers must understand the concepts) and to one of her criteria for students (it must be something that students can understand).

One criterion that P2 suggests as a way of assessing whether content can be understood by students is the idea of useful and preferably concrete representations. She prefers concrete representations, suggesting that this is one problem with tackling photosynthesis. How can this complex, hidden process be represented in concrete ways? In the thermodynamics unit she has found a good heat flow representation even though it is not concrete.

P2 does not believe that any content is absolutely essential from a disciplinary perspective. Therefore, the choice of content is a rather arbitrary process:

> I don't think it's easy to agree on what are powerful ideas or even if you can agree on some. I think the list will end up being very long. And so it's hard to say which ones should be emphasized and which shouldn't. You can imagine people saying, "You mean you're going to teach science and not do any physical science or not life science?" That would cause a lot of alarm. (Tape 121, p. 1)

Depth vs. breadth. P2 advocates teaching a few concepts well and is less concerned with what particular concepts are chosen.

> I think that if we said that it doesn't matter how much you teach, it matters that your students understand two or three key ideas at the end of the year, that that would be quite reassuring to

> teachers and would lead to a lot more interesting science. (Tape 123, p. 15)

P2 uses the heat and temperature unit as a model in this regard. Students explored a few concepts about heat and temperature over a 10- to 14-week period.

Content integration within and across grade levels. P2 talked more about the problem of integration across grade levels than within grade levels. One issue she is debating is whether it is better to have elementary science specialists. She identified several advantages to such specialists. First, they would be more likely to have the subject matter knowledge and interest needed to teach science well. Secondly, a specialist could work with the same group of students across two or more years. This would enable the teacher to build on ideas developed in prior years in meaningful ways.

This would contrast sharply with the "spiraling" of content built into textbook series like SBG, which P2 criticized as not communicating to teachers and students that science is a cumulative endeavor. P2 believes that the publishers consciously left out explicit connections between ideas developed at one grade level and another to appease teachers who will buy the books and not want to depend on students having developed prior knowledge in an earlier grade level. One disadvantage that P2 sees with the science specialist is that opportunities for cross-disciplinary integration get lost. P2 concludes that it is realistically a better choice to go with a science specialist who can "actually come back the next year and do the next thing, and try to build on understanding more sensibly" (Tape 123, p. 17).

Views of Science Teaching and Learning

P2 focused most of her discussion on the curriculum development process and did not elaborate in as much detail as other experts about classroom teaching

strategies and student learning. However, she did give some general ideas about teaching strategies and instructional models that she believes will better promote student learning.

View of the learner. P2 looks at student learning from developmental and constructivist views. She is concerned about how research findings about the active, constructing nature of the learner can be useful in classroom teaching. She points out that it was only in the third reformulation of the materials in the Computer-as-Lab-Partner curriculum that the multidisciplinary team was able to take full advantage of the active nature of the learner. P2 also emphasizes that learning takes time and is a process of conceptual change. She frequently draws from her experiences with students' learning about thermodynamics to emphasize how difficult it is for kids to connect ideas together and be able to use them.

Instructional model. P2 does not articulate a particular instructional model to guide classroom teaching. Instead, she draws from and elaborates on other models, piecing together aspects of each that she finds particularly powerful. For example, she talked about the Learning Cycles model developed by SCIS. She finds their overall framework of exploration, invention, discovery to be very appealing:

> In exploration you sort of play with the things and find out what's there. In invention the instructor says the main concept here is density or floating and sinking. And then in discovery you actually take the concept and try to discover what it means. Then you somehow kind of pull it together. (Tape 2, p. 6)

Her thermodynamics unit, however, seemed to follow a somewhat different model that she described in her written response to our questions. This instructional organization seemed consistent with a conceptual change model of instruction. Students' ideas about natural phenomena were first elicited and discussed. The curriculum then provided a variety of representations of

phenomena for students to consider and to compare to their existing representations. The teacher's role in providing feedback to students was necessary to help students integrate their understanding and build large conceptual structures. Technological tools as well as cooperative groups of students supported the teacher in providing this critical feedback. This feedback encouraged students to reflect on the differences between their own ideas and explanations and the scientific ideas. Students were given a variety of opportunities to use and consolidate their new ideas. P2 points to this as an improvement over the learning cycles model, "pushing it one step further" to provide much more emphasis on reconciliation and consolidation of concepts.

Activities. P2 is critical of the notion of hands-on science. She argues that it is really minds-on science that is needed:

> It seems to me that we've gone from some sort of idea that the way you learn science is from reading a book to the idea that hands-on activities are essential for science. I would like to argue that it's not hands-on activity, but minds-on activity, that we really need. And it's not clear whether you should be reading the book or doing activities or resting in a hammock. The point is that we don't engage the mind of the students in a whole lot of things that go on in science. Mixing together things so that you can get a bubbly mixture or sticking celery plants in water so that you can get red lines running up the sides is all great fun, but if they don't get related back to anything else, then all they are is red lines running up celery stalks . . . unless you can get your mind around that activity, then I think that we've failed. (Tape 123, p. 10)

She is critical of many activities in the SBG series because of their lack of linkage to the curriculum:

> The worst culprits are those activities for the "mainstreamed" students which typically seem hands-on but not minds-on. Students cut out, color, and build things for no obvious reasons. The activities are not shown to be integral to the instruction and often seem just superficially similar (e.g., sing a song, memorize a poem, classify objects). (Written response, Part II, p. 3)

She criticizes other activities in the text as being interesting "but too big a leap" from the limited information children have. She points to the example of

an activity in the fourth grade text where students put bricks in water. Such an activity provides an opportunity to study wave motions, but as represented in the text is it reduced to enjoyable water play.

P2 believes that many creative and potentially useful activities can be drawn from the SCIS curriculum materials. She believes that a major problem with the SCIS curriculum in its current formulation is that it does not provide enough opportunities for students to consolidate and reconcile their ideas with new information gathered from the activities. She advocates pushing the SCIS activities "one step further" to include more student interpretation and reconciliation.

> You probably need to do another cycle. . . . Once you've done those predictions and have failed, then probably what you want to do is bring in a new set of objects and do anther cycle because you haven't consolidated. You have some tentative ideas and you want to check them out a second time around, and that's not there. (Tape 2, p. 8)

She describes a teacher who has developed an "elaborated mode of doing the SCIS activities" that includes a lot of writing and synthesis of ideas.

Although P2 is eager to have activities that push children's thinking and not just their hands, she is also ready to accept even mindless hands-on activities into the elementary science program. She believes that at least the fun of doing such activities would help motivate students to be interested in science. She is disturbed by the ways in which textbook science like SBG "turn kids off to science" and communicate the wrong messages about what it takes to enjoy and be good at science.

Curriculum Development and Teacher Change

In thinking about ways to support teachers in developing the knowledge needed to teach elementary science, P2 focused on curriculum decisions and curriculum materials. Given her experience in the development of the SCIS

program, it is not surprising that her comments focused on curriculum and curriculum materials rather than on changes in preservice and inservice teacher education. In this regard, she qualified her contributions to this analysis: "My contribution is to examine how principles from research on learning and instruction can be used to guide curriculum design" (Written response, p. 2).

The curriculum decisions that P2 thought could support better elementary science teaching have been mentioned in previous sections. First, curriculum content should be personalized. That is, individual instructors should be involved in defining the content that is addressed in a given classroom. P2 believes such a personalized curriculum is necessary because of the "extremely robust and integrated understanding" of subject matter that is needed to help students develop meaningful understandings. "To insure that the instructor has an integrated understanding of the subject matter, a personalized curriculum seems appropriate" (Written response, p. 7). A second curricular decision that P2 supports is a genuinely spiraling science curriculum across grade levels, a curricular goal that can only be achieved if science specialists are used extensively in elementary schools:

> I'd recommend that we had science specialists throughout the elementary school. It's nice to integrate stuff across the curriculum, but my feeling is that the trade-off is not really good right now. . . . I'd prefer to think of us as having specialists who actually came back the next year and did the next thing, and try to build on understanding more sensibly. (Tape 123, p. 17)

In terms of curriculum development, P2 is outspoken in her criticism of the textbooks like the SBG series. In her written analysis of this series, P2 comments:

> This series offers a view of science that is fragmented and even contradictory. It is certainly wrong. On the one hand, many sections start with scientific oddities that would be more at home in the National Enquirer. On the other hand, the scientists featured often primarily engage in cataloguing and description, and the students are encouraged to do the same. This series sends

> the wrong message about the nature of science and will not attract the right students or perhaps any students to science.
>
> If science is the accumulation of isolated pieces of information, this series teaches it.
>
> This series "covers" science and uncovers nothing.
>
> Science is never knowing why and always knowing what it is called.
>
> Thinking is an afterthought found in the chapter review.
>
> This series ignores depth and offers superficial breadth. Coverage includes any topic found in college science courses along with extensive and complex vocabulary but virtually no serious explanation.
>
> Science is questions students don't know how to answer.
>
> Science is sensational pictures.
>
> Scientists collect things and destroy them in the process. (Written response, Part II, p. 1).

P2 believes that curriculum materials can be developed that will be much more supportive of both teachers and students. She draws from her experience with both SCIS and the heat and temperature unit she developed in the Computer-as-Lab-Partner project. She identifies the interaction of a multidisciplinary team in creating, testing, and revising the materials as one key feature of successful curriculum development.

> Ultimately, to improve elementary science curricula, we need multidisciplinary teams of experts including those familiar with classroom practice, those who understand students, those who have developed theories and principles of instruction, those who understand the subject matter, those who understand how technology might be used effectively, those who are familiar with the economic situation of schools . . . and those concerned with preservice and inservice teacher education. (Written response, Part I, pp. 1-2)

P2 describes the development process as one of "curriculum reformulation" in which ideas are tried and continuously refined in light of trials in realistic settings. She thinks it is worth starting with activities already developed by SCIS, Outdoor Biology Instructional Strategies (OBIS), The "Voyage of the Mimi"

curriculum, and others. The multidisciplinary team would then work with each teacher involved to personalize the curriculum, while maintaining a coherent program.

One piece of the design and reformulation process would be to assess the ideas that students bring to science class. Knowing about students' ways of thinking and experiential knowledge could then be used to design appropriate representations for the concepts under study. As the experience of the Computer-as-Lab-Partner project illustrated, this is a difficult process which must be guided by consideration of a variety of different representations or frameworks, as well as by efforts to incorporate understanding of the active, constructive nature of the learner into the construction of a representation. Encouraging students to compare their existing representations of the phenomena under study with those offered by the curriculum and helping students reflect on the differences between these models would be critical aspects of the instructional process.

In the process of curriculum reformulation, P2 advocates consideration of alternative approaches to instruction and a range of methods of instructional delivery. One approach she believes has great potential is the use of technological tools and the use of interactive activities. She suggests the reformulation of activities that are part of existing curricula to make them more helpful to students in developing integrated understandings. She cautions that these activities, in and of themselves, are not guaranteed to improve understanding. Technological tools and hands-on activities have the potential of providing alternative representations for scientific phenomena, but such representations are not necessarily readily integrated by students and may result instead in isolated bits of information rather than systematic understanding. "The process of insuring that students gain integrated

understanding is not yet well understood and likely to be one of the main foci of the curriculum reformulation process."

P2 asserts that knowledge about effective instruction for integration of understanding is available. The research that P2 points to include findings about the importance of valid feedback to students about their ideas, about cooperative learning experiences, and about interactive hands-on activities. In addition, research (including P2's own research) shows that students must be given opportunities to extend principles learned in science classes to naturally occurring problems. Finding ways to integrate naturally occurring problems with those studied in science class is probably idiosyncratic to the knowledge domain under investigation, and research needs to help identify the most profitable applications of concepts in the science curriculum--concepts such as heat and temperature, ecosystems, etc. Thus, P2 believes that research should inform the curriculum development and reformulation process, and also that continued research is needed.

P2 emphasizes curriculum reformulation rather than curriculum development. The kind of reformulation that she describes in her own work goes well beyond the traditional field-testing of new curriculum materials. P2 is not suggesting field-testing for the purpose of making minor adjustments and revisions. Rather, she views curriculum implementation as an extension of the research on student learning: How do students respond cognitively to the instruction? What are more effective ways of helping students become engaged in changing their ideas and in integrating new information into their prior knowledge? This is an intensive process, focusing in detail on individual learner's thinking. And the process does not end with the first reformulation. It continues as long as necessary to produce significant and desired impact on student understanding. This curriculum reformulation then stands in striking

contrast with the usual way in which materials are developed and field-tested. P2 believes that this intensive process will result in the production of materials that are more meaningful to both students and to the teachers using them.

P3: Summary of Approach

Background and Overall Perspective

P3 brings a unique perspective to this curriculum analysis task--that of a science curriculum developer. After 13 years as a university professor involved in research and in teaching educational psychology and science methods courses, P3 took on a new challenge in a nontenured position with a nonprofit curriculum development organization. P3 became associate director of this organization and has been successful in obtaining major grants from the National Science Foundation and IBM to develop curriculum materials. He has just completed a four-year development process for a K-6 science series and is now immersed in a similar process for middle school science.

This development process included an extensive survey of teachers and state science supervisors as well as an analysis of strengths and weaknesses of existing K-6 science materials. This work provided the foundation for the development of a conceptual framework for science and technology education at the elementary level and a set of guidelines for the development of curriculum materials that P3 is now implementing. From the beginning, this curriculum development work was linked with a publishing firm. P3 thus faces the challenges of integrating his knowledge of research with the practical realities faced by teachers and the practical concerns of a publishing house. He is concerned with, as he puts it, taking "the ideas from the academic world or researchers, and the practical issues of teachers, and the marketing problems of publishers," pulling "all of those together in some kind of synthetic way."

P3's background includes elementary science teaching experience in a laboratory school where he used the SCIS curriculum materials. These materials were developed in the 1960s and were characterized by a focus on the development of a few, closely linked concepts which were explored through hands-on investigations by learners. The program stood in contrast with the vocabulary-laden approach of most elementary science textbooks.

P3, like the other university-based experts, has been an active leader in science education. He has written numerous articles and books, including a science methods text. He has assumed a variety of national leadership positions within the National Association for Research in Teaching Science and other organizations. Most recently he has taken on leadership in the National Center for Improving Science Education. In this role he was chair of the panel that developed a synthesis of recommendations for curriculum and instruction in elementary science.

In many ways P3's overall approach to the elementary curriculum is influenced by his experiences as a curriculum developer. For example, he seems much more willing than the other university experts to compromise ideals for practical realities, and his approach tends to be more eclectic than P1. He attempts to synthesize a number of different lines of research into his K-6 series: constructivist views of learning; conceptual change models of instruction; developmental studies by Piaget, Maslow, Kohlberg, and a variety of health educators; the cooperative learning literature; the science-technology-society literature; motivational theory; and research on learning styles. P3 has tried to draw from these research traditions in developing a rationale for content selection and organization and in defining appropriate activities for the classroom. No one body of literature or theoretical perspective seems to frame

his curriculum development work; rather, a meaningful integration of these various perspectives into a new teaching model serves as the core of his work.

One area of emphasis in his work that differs from the other experts has to do with technology and societal issues as being important content in the elementary curriculum. He is a strong advocate for teaching elementary students about technology and its relationship to science. In considering societal issues that are of particular importance to young children, P3 identified health as a critical piece of the science curriculum. Thus, his elementary science series places equal emphasis on science, technology, and health.

Goals of the Elementary Science Curriculum

Because of his comprehensive K-6 curriculum development work, P3 had developed a clear set of ideas about goals of the elementary science curriculum. He began by agreeing with the characteristics that we had suggested, emphasizing the importance of the development of meaningful understanding of a few concepts rather than superficial memorization of many facts and vocabulary words. He argues that we need to "demystify" science by "redefining the scientific and technologic knowledge base in terms of major concepts that are accessible to the majority of people, rather than in terms of minutia that are important and meaningful primarily to the scientific and technologic communities" (National Center for Improving Science Education, 1988, p. 21). The vehicle for doing this is not the traditional "topics" approach to science education. Rather, P3 argues for an approach that focuses on "fundamental and powerful" explanatory concepts such as orderliness, cause and effect, systems, and so forth.

P3 pointed to some important goals of elementary science education that we had not included on our list. He wanted to broaden the goals of science

education in two major ways. First, he advocated the incorporation of technology into the science curriculum. Because we live in such technologically oriented world, each citizen should come to understand technology and its relationship to science and to society. P3 does not simply advocate the use of technological tools (such as the computer) in teaching elementary science. Instead, he emphasizes the need to teach about technology. P3 has a model (Figure 1) to illustrate the relationships between science and technology and their connection to educational goals. In this model he contrasts the origins of scientific knowledge (originates in questions about the natural world) and technological knowledge (originates in problems of human adaptation in the environment), the methods of study in science (inquiry) and technology (problem-solving), and the products of science (explanations of natural phenomena) and technology (solutions to human problems of adaptation). However, he illustrates how both science and technology have social applications and can form the basis of social actions.

In addition to adding technology goals, P3 also suggested that the goals for science and technology should not be limited to acquisition of knowledge. In addition to knowing, students should come to value and do both science and technology. Thus P3 emphasizes three types of curriculum goals: acquisition of knowledge related to science and technology, utilization of process skills based on scientific and technologic inquiry, and development of values and ideas about science and technology in society. Throughout all three of these strands, there is an emphasis on social and personal needs and citizenship goals. In a problem-solving context, students should be provided with knowledge, skills, and attitudes about science and technology that they will find useful in "making responsible personal decisions and taking appropriate individual actions." For example, P3 emphasizes knowledge related to students'

personal matters, civic concerns, and cultural perspectives. In the process skills, he emphasizes decision-making skills and daily living problem-solving skills in addition to the traditional-science process skills (predicting, hypothesizing, inferring, designing experiments, etc.). He wants students to develop dispositions to study and become involved in local issues, public policies, global problems.

P3 is particularly concerned about the failure of existing science curricula to pay attention to the citizenship aspects of science education: "For about 25 years, a quarter of a century, we've forgotten something. What we've forgotten is that science education ought to have something to do with society and personal needs" (Tape 146, p. 1). This emphasis is reflected in the curricular goals defined in P3's executive summary of a design study for elementary science:

> Children should learn about science, technology, and health as they need to understand and use them in their daily life and as future citizens. Education in the elementary years should sustain children's natural curiosity, allow children to explore their environments, improve the children's explanations of their world, help the children to develop an understanding and use of technology, and contribute to the informed choices children must make in their personal and social lives. (Tape 146, pp. 3-4)

It is also reflected in his concern that science education help students think about science and technology-related careers in more serious ways than token pages in the textbook highlighting people working in science careers.

One kind of citizenship goal that P3 emphasized related to cooperative learning. P3 asserted that science education should prepare students to be citizens who cooperate in groups, recognize societal rules, and contribute in positive ways to group decisions. Thus, his recommendations concerning the use of small-group activities in science instruction were not only pedagogical

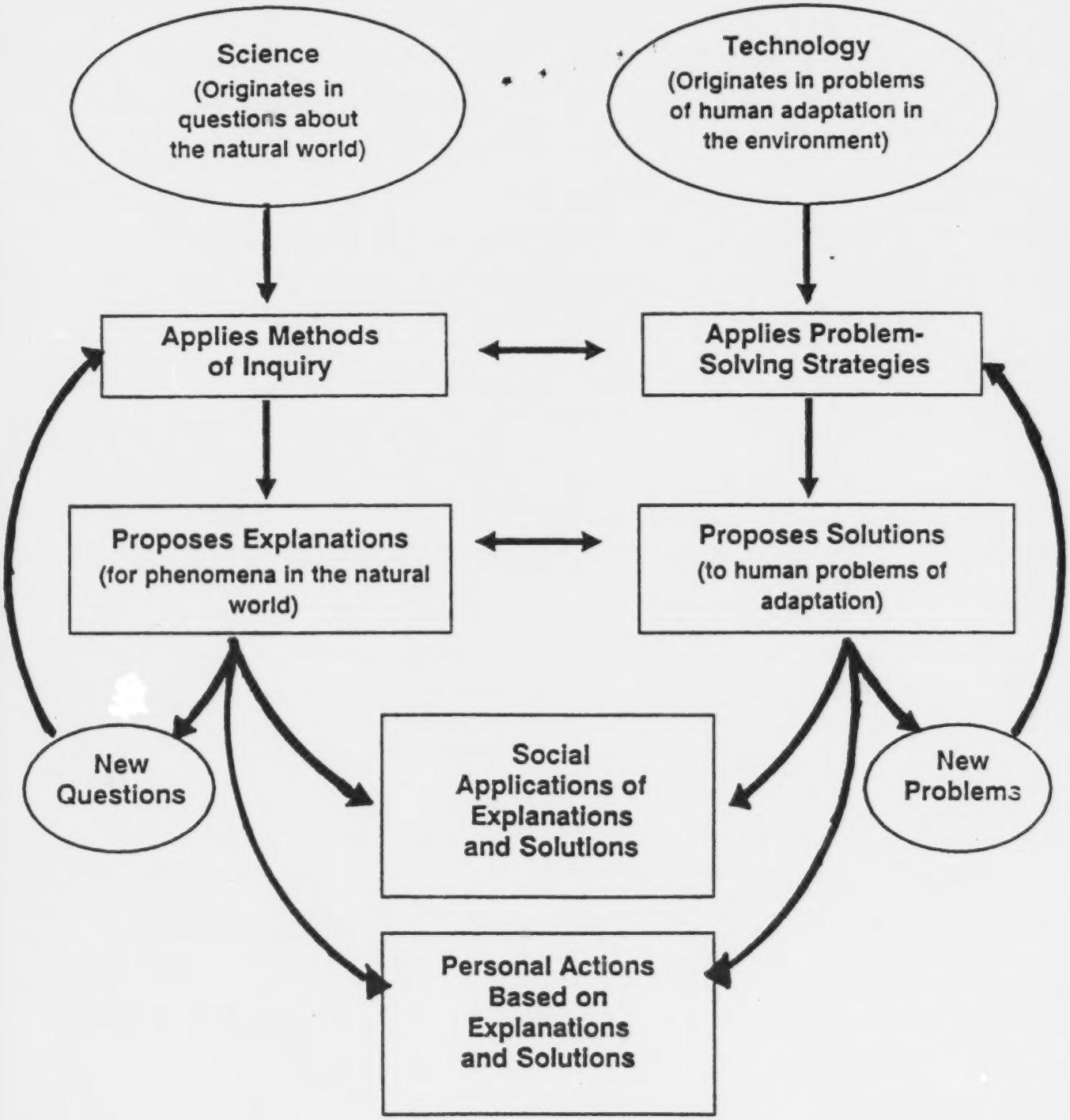
Science
(Originates in questions about the natural world)
Technology
(Originates in problems of human adaptation in the environment)
Applies Methods of Inquiry
Applies Problem-Solving Strategies
Proposes Explanations
(for phenomena in the natural world)
Proposes Solutions
(to human problems of adaptation)
New Questions
Social Applications of Explanations and Solutions
New Problems
Personal Actions Based on Explanations and Solutions

Figure 1. P3's instructional model of the relationships between science and technology and their connection to educational goals.

strategies to help students understand science content; they were also suggested to accomplish citizenship goals.

The K-6 Curriculum: Content Selection and Organization

Criteria for selection. P3 has been through the process of selecting and organizing the K-6 science curriculum, so he was able to detail for us the criteria that he used. In some cases, he pointed out alternative approaches that could have been taken that would have been justifiable.

"I want to keep that picture of the kindergarten child in front of me" (Tape 146, p. 4). Most of P3's criteria could be described as child-centered. He does not start with the structure of the disciplines or with analyses of inquiry processes in science. Instead, he starts with the child. What are some real problems that children face at different developmental levels?

> I think this is a problem-solving orientation, not one that starts from the structure of the discipline and says well this is a key idea that kids have got to understand at some point. . . . My sense of what you're doing here is sort of working back to, well what are some real, real problems that kids are likely to be dealing with at this particular age level or grade level? And now let's work back and begin to talk about what kinds of knowledge, process, disposition they would need to acquire if they were going to deal with those problems. (Tape 146, pp. 6-7)

Thus, P3 is concerned that the curriculum be responsive to students' personal and social needs as well as their conceptual learning needs. He believes that the curriculum should fulfill students' basic needs and prepare them for citizenship as well as help them develop conceptual understandings of science. He believes in starting with students' needs and identifying from that point of view a few central superordinate ideas that could help organize the curriculum.

Because of his focus on students' needs, he argues that some of these "big ideas" should be health-related in the elementary grades. Instead of focusing on larger societal needs such as acid rain and population growth, we should focus on the problems children face in their society. And health is a natural

concern in children's society. P3 finds the health education literature to be particularly compelling in helping define developmental criteria for health content. Health educators have data indicating the kinds of illnesses and injuries that children experience at different ages:

> I was impressed with the fact that you go to the health educators and they know when to introduce . . . they know when early adolescents start becoming sexually active. They know when they start experimenting with drugs and so they say okay that's coming at about the fifth- or sixth-grade level. . . . What we want to do is design our health education programs to precede that. (Tape 146, p. 4)

P3 challenged his curriculum development team to find similar criteria in selecting organizing ideas in science and technology. What kinds of problems would a 6-year-old or a 10-year-old have to deal with? What are the personal and social needs of the child? What citizenship goals are appropriate to address? These questions guided the selection of content in three content strands of P3's curriculum: the science strand, the technology strand, and the health strand.

In the science strand, P3 and colleagues selected one major science concept and one process skill to organize instruction for a grade level. The concepts they selected were order (first grade), change (second grade), patterns (third grade), systems (fourth grade), transformations (fifth grade), and balance (sixth grade). P3 recognizes that the choices made were arbitrary in many ways but were also developmentally justifiable. For example, order seems appropriate for first grade because it relates to the first graders' world and concerns:

> Why order and variation in the early years? My response is, Well let's look at this. Knowing about order and disorder in one's world relates some to safety and what one does and how one acts. Order and disorder have to do with physical realities and how things are working and not working. Distinguish right and wrong. Take the order out of the context of an ordered universe and what do Mom and Dad and principals and teachers want? Order. And that gets translated to right and wrong things to do in the classroom and so there's something about that. Recognizing different points

> of view but there may be different orders and understanding rules are based on we want some order in here and so we have rules to bring that about. So underlying that is something like order. (Tape 146, p. 5)

However, the concept of order is arbitrary in the sense that you could do some interesting things with that concept at the sixth-grade just as well as at the first-grade level. P3 turned also to the disciplines to justify conceptual choices, arguing, for example, that it makes sense to study order before systems.

P3 pushed his team to select only one organizing concept for each grade level so that students would have the opportunity to explore that concept in different contexts. Since the different contexts would include both health and technology as well as science, one criterion for selection was that the concept not be unique to science. P3 used that to explain why photosynthesis or the kinetic molecular theory would not be good unifying concepts in this curriculum. They do not easily apply in health and technology contexts.

P3 acknowledged that different criteria for content selection could have been used. For example, the curriculum could have been built around skills as was done in Science--A Process Approach (AAAS, 1970). Alternatively, the content could be built around careers. One could begin with a plant physiologist and study science from her/his perspective. Another approach is to organize the curriculum around science-technology-society issues such as acid rain, world population, mineral resources, world health, and so forth. "From my point of view, those are all legitimate ways to organize a curriculum. They have different goals, a different orientation. It isn't bad. It's just different . . . a different means to an end" (Tape 146, p. 9-10). The two main criteria P3 identified his team as using were the major conceptual ideas in science and the major process skills.

The process skills selected for emphasis were organization (first grade), measurement (second), prediction (third), analysis (fourth), investigation (fifth), and decisions (sixth). In contrast with the selection of concepts, P3 found the process skills easier to organize in a developmental hierarchy. The skills that first graders can tackle are different than those appropriate for sixth graders. P3 describes the lower level skills as informal inquiry skills (measuring, classifying, comparing, contrasting, analyzing, synthesizing). He contrasts these with formal inquiry skills that can develop in Grades 4-6: identifying problems, formulating hypotheses, predicting outcomes, separating variables, controlling variables, exploring decisions, evaluating decisions, making decisions, acting on decisions.

A final criterion for content selection in P3's child-centered view was student interest. His instructional model calls for engaging student interest as the first step. He argues that you need to use children's curiosity and interest to establish a foundation you can build on.

Depth vs. breadth. Like the other experts, P3 is a strong advocate of depth over breadth. In the curriculum materials he has developed many of the traditional topics of elementary science are omitted. Instead, the curriculum focuses at each grade level on the development of one conceptual theme and one process skill theme across a science unit, a technology unit, and a health unit. For example, fifth graders study transformations and investigation in a science unit on energy chains and food chains, in a technology unit about design and efficiency, and in a health unit on fitness and protection.

Content integration within and across grade levels. P3's discussion focused more on content integration within grade levels than across grade levels. A primary goal of his K-6 curriculum is to integrate conceptual themes across each grade level. This conceptual integration is enhanced by an

introductory unit at the beginning of the year and an integration unit at the end of the year. By moving away from a topic organization, P3 believes the curriculum integration is improved. No longer is the curriculum a series of topics studied in isolation from each other. Most of P3's discussion of concept organization across grade levels focused on the developmental organization. He did not talk about the extent to which the curriculum is designed to help students gradually build understandings of concepts across the grades.

Views of Science Teaching and Learning

Multiple views of the learner. P3 uses a variety of theoretical lenses to look at the learner. He points to these new views of the science learner as having important implications for science teaching: "Programs based on new conceptions of how children learn science employ radically different teaching techniques to which science teachers must adapt" (National Center for Improving Science Education, 1988, p. 155). Constructivist views of the learner suggest, for example, that children's prior experience and knowledge of science and technology provide an essential foundation upon which teachers can frame a science program and base instruction. This theoretical perspective also supports the "less is more" emphasis. "Studying a subject in depth gives students more time to become actively involved (mentally and physically), to explore phenomena, and to construct explanations of the natural world" (National Center for Improving Science Education, 1988, p. 156).

But P3 does not limit his perspective to constructivist theory. He also draws from literature about student motivation to learn, Piagetian views of developmental stages, and the learning styles research (Kuerbis, 1986). For example, these theoretical perspectives suggest to P3 that hands-on activities and cooperative learning are appropriate teaching strategies.

Thus, several assumptions about students serve as the basis for the design of new curricula. As P3 writes in his curriculum design report:

> These assumptions include the following: students have motivation, students have developmental stages and tasks that influence learning, students have different styles of learning, and students have explanations, attitudes, skills and sensibilities about the world. (Written document #2, p. 4)

The personal and social needs of students is also an important piece of P3's vision of the learner. In thinking about the health curriculum, he identified times when a behaviorist view of learning is more appropriate to meet students' needs than a constructivist perspective:

> Within the health component, to the degree possible, we have tried to take a behavioral approach which is an interesting kind of problem because it is not a conceptual change approach. It's change the <u>behavior</u>. . . . Take smoking as a good example. Every smoker . . . knows that smoking is not good for you . . . but they smoke. They behave in that way and so the health educators have started saying, don't teach the systems of the body. It doesn't make any difference what people <u>know</u>. (Tape 145, p. 8)

<u>Instructional model</u>. P3 and his colleagues have developed an instructional model that he characterizes as the "best generic approach to a conceptual change model of instruction" (Tape 148, p. 6). The model consists of five phases, which serve as "a master template upon which teachers can design daily lessons, weekly or monthly unit plans" (National Center for Improving Science Education, 1988, p. 46). The stages are engagement (students become mentally and physically engaged in the concept, process, or skill being introduced), exploration (through activities students actively explore their environment), explanation (students verbalize their conceptual understanding and teachers introduce formal terms or definitions), elaboration (students have opportunities to practice the desired skills and behaviors), and evaluation (students assess their understanding and teachers assess progress toward achieving educational objectives). The use of the "e's" in this model is deliberate: It

serves as a mnemonic for teachers. P3 likes the generality of the model and sees it applying to skill development as well as concept development. He describes how a similar model could help teach students how to use a microscope, for example.

Activities. P3 stresses the importance of hands-on activities in the learning process. In his curriculum development work he has identified a number of different criteria that should be considered in selecting appropriate activities. The criteria vary by grade level as shown in Table 2. P3 explains that these criteria served as guidelines for the curriculum writers of his K-6 series: "The more you can check off, the stronger the justification for that activity or that series of activities or that unit" (Tape 146, p. 3). P3 summarizes some of the key characteristics of instructional activities:

> -The curriculum is based on developmental stages and tasks of students.
> -Activities focus on the students' lives and their world.
> -A student's personal and social context is used to promote healthy behaviors and to develop scientific, technologic, and health concepts and processes.
> -Activities contribute to learning the basics of reading, writing, and mathematics. (Written document #2, p. 4)

Social climate. P3 strongly advocated the use of cooperative learning strategies in science classrooms. He saw effective small-group work as enhancing a variety of goals including conceptual learning and social development. The K-6 series he has developed emphasizes cooperative learning strategies. In P3's view of cooperative learning, it is essential that teachers not view this as simply putting students in groups. Instead, P3 emphasizes teaching the students how to set up group norms, how to structure groups so they function. This means defining roles within groups (recorder, messenger) and focusing on teaching students how to operate as a group. P3 has built in regular cooperative learning guidelines for teachers in his curriculum materials.

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Teacher Education/Teacher Change

P3 recognizes that teachers will have to undergo significant conceptual change themselves in order to use his curriculum materials effectively. They need to change, for example, their views of learners and learning. How is P3 helping teachers who are piloting his materials undergo such change? P3 insisted to his publisher from the beginning that teacher training be incorporated into the final product package. Thus, when schools buy his program they also get a service contract:

> What the service contract means is you get four staff development programs during the year, you have an ongoing consultant who will come to your district, and you'll have trainers of trainers so we will try and set up the staff development for the school district. (Tape 145, p. 5)

P3 contrasts the reality he faces with the ideal. In reality, his approach has been primarily a learning-by-doing approach: Teachers use the curriculum materials and as they use them they start to develop new understandings of science teaching and learning. P3 basically says to the teachers, "Trust us." He describes this phase as hand-holding: The teachers just need to try it their way for a while even though they do not fully understand the goals and rationale for the program. Ideally, P3 would like to see teachers' work restructured in ways that would give them time to be more thoughtful and reflective about the goals of the science curriculum.

P3's pilot teachers for his series received a weeklong workshop prior to using the materials. As they taught with the materials, the curriculum developers sent an implementation specialist to work with a leadership team of teachers about four times over the school year. The idea was to develop a "trainer of trainers" model. However, P3 acknowledges the hesitancy of the trained teachers to take on this leadership role within their buildings. The teachers were uncomfortable running workshops for their peers.

Table 2

P3's Criteria For Selection Of Activities

Grades 1-3	Grades 4-6
Basic Needs -Fulfilling safety and belongingness needs	Basic Needs -Fulfilling belongingness and self-esteem needs
Health Risks -Preventing unintentional injuries -Avoiding abuse and neglect -Encouraging dental health -Becoming physically fit -Establishing nutritious diets	Health Risks -Preventing unintentional injuries -Avoiding abuse and neglect -Avoiding substance use and abuse -Preventing teenage pregnancy -Establishing nutritious diets -Becoming physically fit -Becoming mentally healthy (depression and suicide)
Developmental Tasks -Developing concepts necessary for everyday living -Developing conscience, morality, and a scale of values -Establishing basic academic skills -Resolving issues of initiative, guilt -Making a transition from preoperational to concrete operational thought	Developmental Tasks -Achieving personal independence -Learning to get along with peers -Learning appropriate social roles -Resolving issues of industry and inferiority -Learning to handle the tools of society -Making a transition from concrete to formal thought
Preparation for Citizenship -Developing respect for family and peers -Recognizing school rules -Making personal decisions	Preparation for Citizenship -Cooperating in groups -Recognizing societal rules -Making group decisions

Curriculum Development

P3 describes the curriculum development model they are using as "top-down." He assumes that teachers will take the curriculum and change it to make it their own. However, he wants them to try the curriculum as designed first before altering it. For example, he is frustrated with teachers who want to use just one or two of the units at a given grade level. He would like them to use the whole sequence and see the power of that before dropping certain units entirely.

His curriculum model could be described as research-based as opposed to research-driven. Certainly, for example, his model includes paying serious attention to research on student learning and effective teaching strategies. His model also includes an evaluation phase of development that provides feedback about revisions of the materials. However, this evaluation process does not include research on students' learning in the kind of depth advocated by P1 and P2. Thus, while research is informing the development of the materials and their evaluation, the process is not driven by focused research on the kinds of understandings that students bring to instruction or develop during instruction.

As mentioned in the last section, P3 believes that teacher training should be incorporated into curriculum development models. He is trying to come up with a way of making that attractive to publishers. Inevitably, this involves compromises. P3 recognizes that the amount of teacher support needs to be much greater than his pilot teachers are receiving.

P3 is frustrated with the fast pace of curriculum development. He is under contract to produce essentially one unit a month when it would be more appropriate to develop one unit a year. He did not seem very hopeful that

this time factor could be changed and was willing to accept this as a realistic constraint on the curriculum development process.

Comparison of the University Experts

All three of the university-based experts drew heavily from research in articulating their views about the ideal elementary science curriculum, and all three seemed particularly intrigued with the conceptual change research on student thinking and with the research on cooperative learning and the social nature of learning. However, they had different visions of how this research should inform elementary science curriculum and instruction. P1 pulled together these two lines of research to develop a focused view of science learning as social constructivist in nature and of science instruction as best organized around a conceptual change model. Conceptual change and social interactions that support conceptual change were at the heart of his vision.

Both P2 and P3, in contrast, were more eclectic in drawing from the research literature. While the conceptual change research informed their thinking, they also attempted to integrate other lines of research--including Piaget, Maslow, Kohlberg--with conceptual change research. P2 was not yet ready to draw together this research into a focused model of learning and teaching. She argued that the research is still in process, and that we should still be searching for answers and models. P3 articulates a model, but he concedes that it is a "generic" model--engagement, exploration, explanation, elaboration, and evaluation--and an eclectic model that is supportive of conceptual change goals but not limited to that view. Thus, his model draws widely from research on learning styles, developmental stages, values development, conceptual change, cooperative learning, and so forth, in contrast with P1's model that uses research in a more focused, selective way.

The university-based experts also differ in their views about what it will take to support teachers in implementing the kind of science curricula that they advocate. P1 and P2 both argue for a new model of science curriculum development that is closely integrated with research on children's thinking about science phenomena. P3 views such an approach--taking a year or two or three to develop a unit instead of a month--as ideal but not realistic. His curriculum development model is a top-down process, with the developers creating materials and training teachers to use them. He asks for the teachers to "trust us" and try the materials "our" way before adapting them.

In contrast, P2 argues for a personalized curriculum development process in which classroom teachers are integrally involved in the development process. Like P2, P1's current work in curriculum development involves teachers at the ground level and includes detailed analyses of student learning and thinking followed by what P2 calls "reformulation" of the curriculum. The curriculum materials go through several iterations, each followed by careful analyses of the impact on student understanding. Operating in this framework, P1 and P2 are challenging the status quo in approaches to curriculum development while P3 is investigating what is possible within a more traditional paradigm.

The experts all believe that conceptual understanding should be a key goal of elementary science instruction, and they agree that the important thing is for students to develop deep understandings of a few concepts. However, they think about defining these key concepts in different ways. P3 defines super-ordinate concepts that organize a year of instruction--concepts such as order, change, systems. P1 does not think that such "metaconcepts" will provide useful frameworks for student learning. These concepts are too big and too

abstract for students to link to their experience in meaningful ways. He argues for organizing the curriculum around concepts that are not quite so big: light, energy, photosynthesis, ecosystem, and so forth. The important thing is that students not be exposed to too many of these concepts at once and that they be supported over time in making links among the concepts and in using the concepts to explain events in their experience. P2 defines the conceptual content at a similar level as P1, but she adds an additional criterion for selection of the big ideas: The big ideas should be concrete rather than abstract. In this regard, concepts like photosynthesis are too abstract; heat and temperature are moderately abstract but are more directly within students' experience.

Beyond conceptual goals, the university-based experts differ in how they formulate other goals of the science curriculum. P1 views conceptual goals as central, with all other goals (attitudes toward science, values, cognitive strategies, problem solving, nature of scientific inquiry) growing out of coherent conceptual development. Students will learn about science processes, for example, as they use them to explore meaningful problems and develop new conceptual explanations. P3, in contrast, sees at least three different coequal goals of science instruction--science concepts, science processes and attitudes, and science citizenship. Among the three experts, P3 is the only one who argues strongly that citizenship education be an explicit goal of science instruction and that science-technology-society issues (including health) be a major focus of the science curriculum. His commitment to these goals is reflected in the K-6 curriculum materials he is developing, in which the science curriculum is divided into thirds: science, technology, and health (societal issues).

P1 argues against societal issues as a major goal of elementary science instruction, asserting that meaningful investigation of such issues must be based on complex conceptual understandings. Students would have to tie together understandings of natural phenomena as well as understandings of social and political processes. Without such conceptual understandings, P1 argues, societal issues get reduced to "shoulds" and "shouldn'ts" based on the authority of the teacher or the text rather than on conceptual understanding. P2 takes an intermediate position, suggesting that science-technology-society issues would make the curriculum interesting and exciting; however, she does not see them as essential in a good elementary science curriculum. She views a major goal of elementary science instruction as getting students interested in science and in possibly pursuing science as a career. Neither P1 nor P3 emphasized this as an important goal; they were more focused on the goal of having science make sense to <u>all</u> students, not just the elite going on to pursue scientific careers.

The Teacher Experts

Having summarized and compared the views of ideal curriculum advanced by the three professors, we now turn to the views of the three exemplary science teachers.

T1: Summary of Approach

Background and Overall Perspective

T1 is a third-grade teacher who has taught for 13 years. Although he does not have a special background or teaching assignment focused on science, he participated in a four-week summer workshop for elementary science teachers two years prior to this study that stimulated him to rethink his science teaching. The workshop was conducted by a university science education expert and introduced T1 to new ideas about student learning in science. T1 was particularly

intrigued with ideas about student misconceptions and the role they play in students' learning. As part of the workshops he read research articles about student misconceptions and about conceptual change models of instruction and found the ideas useful in thinking about his own teaching of science. As part of this workshop work and follow-up activities, T1 had the opportunity to develop, teach, analyze, and reteach a unit on light and shadows using a conceptual change orientation.

These experiences had an impact on T1 and challenged him to rethink his own teaching approaches in science. During the interview, he frequently made reference to his light and shadows unit to describe the ideal curriculum. He contrasted this unit with his teaching of other units, acknowledging his frustration that he has not had the necessary time and support to develop appropriate conceptual change strategies for other units in science. Thus, we would characterize T1 as a teacher in transition. He has some focused ideas about what elementary science instruction can and should look like while recognizing that he needs additional support in putting these ideas into action in his own classroom.

T1 values research and teacher development opportunities as ways to improve elementary science teaching. He suggests that research can play an important role in identifying student misconceptions, in identifying activities and questions that will challenge students' thinking, and in providing teachers with insights about the variety of possible ways that students may respond to questions and activities. T1 takes on a researcher role himself as he teaches his light and shadows unit. He uses his students' writing in journals as one source of information about students' developing understandings. In addition, he keeps a daily journal himself, reflecting on the day's lesson and evidence

of student thinking. He uses this journal writing to refine his approach to teaching about light and shadows.

Like P1, T1 brings a conceptual change orientation to this curriculum analysis task. This orientation is consistent throughout his work on the various phases of analysis for this study. In designing sample lessons, for example, he begins by establishing a problem that will elicit students' ideas and get them talking about their ideas. He then has them working in small groups on a task designed to challenge their thinking. Discussion focuses on the development of scientific explanations; students debate ideas and challenge each others' thinking. The teacher asks probing questions and provides feedback to guide student thinking. Assessment strategies focus on describing students' developing conceptual understandings, not on students' ability to recall facts. In his analysis of the SBG text series, T1 consistently looked at the text from the students' perspectives: Would this text be likely to support students in changing their ideas and developing meaningful conceptual understandings?

Goals of the Ideal Science Curriculum

T1's goals for the elementary science curriculum focus on conceptual development and application of concepts to everyday phenomena. He is concerned that all students develop meaningful understandings of science concepts, especially the less verbal students and students who have less rich experiential backgrounds. He believes that traditional science teaching does not make such understandings possible for all students. Like P1, T1 suggests that students will develop a rich understanding of the nature of science and will develop the disposition to inquire and make sense if they are immersed in a curriculum focused on concept development:

> There was a lot about scientific process [in the SBG text], and there were some places where they would ask open-ended questions like "how would you solve this?" But as far as the kind of

> teaching I believe in, they didn't do a lot of having them be skeptical about new ideas. I think that when you get into a lot more interstudent discussion and justifying explanations and giving reasons for why they think something is right . . . that's when you really get into developing a skeptical view. (Tape 91, p. 16E)

Thus, T1 does not talk about the dispositions to inquire or the development of thinking skills as explicit goals of the curriculum. Rather, they will grow out of students' engagement in conceptual learning.

In his written response to the key features of ideal curricula we had suggested, T1 agreed with the emphasis on balancing breadth with depth to ensure conceptual understanding and the emphasis on relationships among ideas and the application of ideas in a variety of contexts. His elaborations of our suggested features clearly emphasize a conceptual change orientation and a constructivist view of learning. For example, he disagreed with the key feature that the curriculum should "provide students not only with instruction but also with opportunities to actively process information and construct meaning." T1 reacted:

> My disagreement would be with the word "instruction." If this refers to lecture, traditional discussion of readings, or teacher demonstration of experiments, then it is not ideal, nor even desirable. Elementary level students do not have the ability to develop conceptual understanding of powerful ideas through these methods. The emphasis should be on the second part, that is, "opportunities to actively process information and construct meaning." (Written response, p. 1)

T1 adds to the key features of the ideal curriculum four other components, each linked to a conceptual change orientation:

> 1. Diagnosing students' misconceptions as a starting point for lesson planning.
> 2. Providing students with the opportunity to represent their understandings and explanations of concepts.
> 3. Providing an effective way of evaluating learning as described in c, d, and e of "Features of an Ideal Curriculum."
> 4. Providing teacher training for successful use of curricula such as described in these key features. (Written response, pp. 1-2)

In describing these additional ideal features of the science curriculum, T1 suggests that the teacher must take on new roles in implementing such a curriculum. For example, he states that students' conceptions must be diagnosed, both in "a general way, by researching misconceptions held by children at different developmental levels, as well as specifically with students in a particular classroom. This needs to be an ongoing process throughout a unit of study" (Written response, p. 1). Thus, the teacher takes on a researcher/diagnostician role. In addition, the teacher must be able to engage students in a variety of representations of science concepts. These representations should include "drawings, graphs, models, writings." Class discussions should accompany these representations, and the nature of such discussions is quite different than what most teachers are currently practicing. Additionally, the teacher must develop new ways of listening to children and of assessing their learning.

Higher Level Thinking in the Ideal Curriculum

T1 was quite critical of the way that the SBG and other science textbooks characterize higher level thinking. He describes comparing, classifying, and generalizing as the types of skills that are traditionally thought of in texts and in science as higher order thinking skills:

> It just strikes me sometimes the way text series set things up, it's like they have this idea that classification and comparison and those types of thing are the end all and be all. . . . It's like they almost suspect that you do those things over and over enough that you're going to learn how to be a scientist. I guess I just want to temper it more with other aspects of science and other ways of doing things. (Tape 91, p. 12)

He notes how textbooks often put these words, "classification" and "comparison," in the margins in dark print as if they were skills that were being taught in a particular lesson. T1 agrees that it may be important for students to learn to take "plants and animals and contrast them according to

what they need to survive . . . be able to make comparisons, to group things into categories" (Tape 91, p. 6). But he believes that opportunities for students to explain ideas and to explore the "why" questions often get left out in this emphasis on the development of specific "higher level" skills.

In contrast with this emphasis on discrete thinking skills such as comparing and classifying, T1 defines higher level thinking as "the type of thinking that's going to get [students] to change their misconceptions" (Tape 91, p. 6). Students have to go through a process of thinking about whether their ideas are right or if their ideas are different from someone else's. They have to "meld" ideas together. In addition, they need to apply ideas to new situations. Can they apply their knowledge and "bridge it over" to other contexts and phenomena in their experience?

The K-6 Curriculum: Content Selection and Organization

"It's like we're all into information and not much into ideas," said T1, who would like to change the content and organization of the elementary science curriculum so that ideas and concepts are at the core of the curriculum. He suggests several criteria that should be considered in selecting and organizing content. First,

> we should distill the parts that really are things that kids can conceptualize and go with that, and maybe that means throwing out all that information and going back. Maybe we should be just taking everything, all this stuff we have from K-6 and take the last two years of that and kick them up to junior high . . . and taking the K-4 stuff which is maybe stuff that can really be conceptualized by K-6 graders and really go into depth with those things and really build something that they can understand and use. (Tape 91, pp. 18-19)

Clearly T1 is thinking about ways of increasing depth over breadth in the science curriculum. Of course, T1 also suggests that some of the "stuff" in the K-4 curriculum may not be concepts that can be well conceptualized by young students. In judging whether a concept can be understood by students, T1

emphasizes thinking about students' experiential knowledge. Do they have experiences that they can connect the scientific concepts with? He questions, for example, how meaningful it is to teach young children about space:

> Kids are always excited about space. They always want to learn the planet names and that this planet has this many moons . . . [but] to try and bring that down to a level where they can conceptualize . . . where do you start? Should you just spend the whole time on motion and laws of motion? . . . I mean it's interesting to adults, teachers like teaching it and it's interesting to kids for them to hear about it, but for them to conceptualize that a light year is that far or it takes this long to get to another planet, they really can't conceptualize that. (Tape 91, p. 18)

T1 suggests that it might be more appropriate to talk about motion in the context of marbles and bouncing balls against walls, experiences with which kids are familiar, than to talk about space.

T1's discussion of space concepts included some discussion of student interest. Should student interest be an important criterion for content selection? T1 warns that such an interest criterion can be misleading and not likely to help us identify ideas that kids can understand in deep and meaningful ways. In the SBG text, he points to the dinosaurs unit in the second grade. Why is it there? Because kids love dinosaurs! T1 suggests that it makes sense to pick things that children will be interested in, but only if you can use that subject to explore some important scientific concepts.

T1 notes that the SBG text tackled only superficially issues about evolution and extinction and focused the unit more on naming and describing the different kinds of dinosaurs. T1 characterizes the resulting chapter as "'Let's talk about dinosaurs.' . . . It wasn't working towards the higher goal of these things, it was more 'here are the dinosaurs.' They got into a lot of vocabulary which to me was really overdone for elementary kids" (Tape 91, p. 17). T1 suggests letting kids memorize names of dinosaurs if they are

interested in that, but not calling it science. Maybe it could be an interesting spelling challenge, instead.

"Fun" should also not be a criterion for content selection according to T1. The SBG text includes a worksheet in which kids shade in a picture to spell out the word dinosaur. "Fun activity, great for indoor recess, but as far as developing any science concept, really there's nothing there" (Tape 91, p. 29).

T1 also does not use science and society issues as an important criterion for content selection at the elementary level. For example, in his sample lessons on ecosystems, he did not bring in ideas about pollution and the human impact on ecosystems. T1 viewed that content as more appropriate for the social studies curriculum and felt that an emphasis on humans could distort children's developing understanding of nature and ecosystems.

> I was just picturing a little bit less emphasis on humans as the central figure in the whole scheme. It seems like if you start to get to those issues, then you are more or less saying that the reason an ecosystem is there is because humans are where it's all leading to. (Tape 91, p. 13)

T1 suggests a research approach to selecting and organizing content. He proposes research studies about children's conceptions of important science concepts. Such developmental studies could be used to identify those concepts that children are ready to understand at different developmental levels. He guesses, for example, that the sixth-grade chapter on animal adaptations in the SBG series could have been studied earlier--that kids would be ready for it earlier. He makes this assumption based on kids' experiences with animals in their environment, such as squirrels. Because it can be related to young children's experience, young children might be able to develop meaningful understandings of it. "Talk to kids and see what they really think about it, and then you could go from there" (Tape 91, p. 20).

While T1 believes that content should be selected because it is related to children's experiences, he also believes that the content should provide conceptual tools for students to apply their knowledge to new situations in their experience. Thus, another criterion for content selection should be its wide applicability. T1 emphasizes the importance of multiple opportunities for students to apply ideas to real-world contexts.

T1 talked primarily about criteria for content selection. He did not say much about how that content should be organized either within grade levels or across grade levels. T1 acknowledged that he found the task of sketching out concepts about ecosystems across the grade levels to be a "mammoth" task. He bumped up against the limits of his own knowledge of science in doing this task, and found himself relying on other experts. He wished he could find the research that must have been done

> about what basic ideas are really fundamental to kids understanding higher level things. . . . If you want kids to be able in high school to really comprehend astronomy ideas and understand about the motions of the planets, what beginning ideas do you need to know? I mean that would a first grader begin to be thinking? (Tape 91, p. 20)

Views of Science Teaching and Learning

Social climate. In his vision of conceptual change teaching, T1 sees the "whole atmosphere like that we're all learning." He tried to "develop a spirit of 'We're all trying to solve things, we're all trying to learn stuff'" (Tape 91, p. 9). Like P1, he sees the classroom social climate as a key to successful conceptual change teaching. He talks about trying to create a "mood" in which people share their ideas and challenge each others' ideas. At times, T1 describes this climate in ways that sound like an extreme version of a discovery approach:

> I just try to make the atmosphere in the room that it's very nonthreatening. Like I try and take four and five answers from different people rather than say this one is right and really let them discover it's right, let them give the evidence, or when they

> go in their small groups they make the discoveries or they see that this really is the way it is and then we come back and talk about it. So I try to get away from, I mean you still say, "Good, you were right," if John gives this prediction that turns out to be the way it is, . . . but it doesn't come across, at least the way I do it, that great John was right and you guys were all wrong. (Tape 91, pp. 7-8)

On other occasions T1 makes it clear that he does not just accept anyone's explanations as good and that the teacher plays a key role in guiding the students' developing conceptions:

> You're persistent. I mean when they give an answer you just say, "Well why do you think that?" And if they don't give you a reason why or they just say "because," you've just got to keep pursuing it and keep badgering them, and they start to get used to it after a while. They know that, well, this joker's going to ask me for a reason, so I can't just raise my hand, say, "The capital of this is such and such." Now I'm going to have some way to back it up. It's just a matter of practice, you just have to do it over and over again and get them used to that mood. (Tape 91, p. 29)

Students and learning. T1 stood out among our experts as a person who constantly thought about his students as individuals. He did not generalize his ideas across students, but instead thought carefully about how different ideas or activities would effect different students. He was critical of the SBG text for trivializing and minimizing the differences among students. The text, for example, always gives one suggested student response to teacher questions. T1 is bothered by this, because he sees that as encouraging teachers to listen for the right answer rather than to listen to children's thinking:

> It [the text] doesn't give any instruction about what if the kids say any of the thousands of other things they might say when ask them that question. It's just limiting, it's assuming that all kids, or even most kids, have the same experiences and that you can build on that, and you really can't. (Tape 91, p. 26)

T1 seems to value conceptual change teaching approaches for their success in challenging and involving all kinds of students. He believes that the quiet, less verbal kids can really benefit from this kind of instruction:

> I haven't found any problems at all with the kids who are; in fact a lot of the time the kids who are normally quiet, if you really call on them and ask them to explain something, you will really get some interesting explanations, and you will find that they come out with some things that really make sense. (Tape 91, p. 7)

T1 also is impressed with the benefits for students who lack rich experiential backgrounds:

> Occasionally you'll get kids who either haven't had a lot of experience with science, or their parents didn't really do a lot of things with them when they were growing up or read to them or anything, and they're a little bit behind in experiences and they're a little hesitant to say things. You'll ask, "Where do you think the shadows are going to be?" and they'll just kind of sit there . . . they don't want to give an answer; usually you will get an answer out of them. (Tape 91, p. 7)

The brighter and gifted students are equally challenged by the kinds of questions and predictions that T1 advocates. T1 told a story of one of his "gifted" students who made a prediction about where a shadow would be and gave elaborate reasons to support his hypothesis. His prediction turned out to be wrong, and T1 was impressed by the equalizing quality of this instructional approach. "Even the bright kids make mistakes," and all the students feel caught up in a learning puzzle together with the teacher (Tape 91, p. 9).

Although T1 did not articulate an explicit theory of learning, it is clear that he held a view of learning that is consistent with a constructivist orientation. He emphasized that students were makers of meaning and that instruction must focus on engaging students in reasoning and thinking through their ideas. He was opposed to a view of teaching as telling and emphasized that for students to understand they must discover relationships and ideas themselves. He did not mean by this that students should be left on their own to rediscover all of science; rather, students need to be guided in constructing knowledge and not given knowledge. It was clear that T1 valued

and respected his students' thinking and felt that such valuing of students' conceptions was a critical piece of successful learning.

Activities. T1 was not an advocate of activities and hands-on science. Instead, he advocated meaningful representations of science concepts. By this he meant that students need to have the opportunity to construct and interpret a variety of representations of the same ideas in order to develop understanding of concepts. Useful representations may include graphs, student writing, diagrams, models, activities, and so forth. T1 is highly critical of activities for activities' sake or activities that are just for enjoyment and do not lead to some conceptual development. In looking at activities in the SBG text and in his own textbook, T1 was frustrated with activities that had potential for application but were set up in ways that promoted learning of facts or information rather than fostering thinking.

In his own school district's text, for example, sundials were used in a unit on light. Instead of using sundials as a context for talking about light and shadows, however, T1 described how the text basically gave information about sundials:

> You can use sundials to talk about shadows if you use it in the right way, but the way it was used here was more, "Sundials are interesting and they were used by people at one time because they did these different things, and the thing about the east, west, north, south." (Tape 91, p. 21)

In the SBG text, T1 criticized activities that were framed in ways that communicated inaccurate messages about the nature of science and scientific thinking. In the third-grade text, for example, students were given four different kinds of seeds and set them up to germinate. They were asked to predict which ones would germinate first. T1 was frustrated with this mindless predicting:

> They didn't ask at all why do you think, I mean do they think it's because this seed is large and the other ones are small? . . . That's where you get into the concept development. . . . If you do that, then you're giving the kids the idea that scientists make guesses all day. (Tape 91, p. 28)

T1 was critical of activities that are selected because teachers like them or kids think they are great fun. He was also critical of activities that purport to engage students in the scientific process, but that do not really foster conceptual development:

> It seems like there are more hands-on things because we're trying to make kids look like and feel like scientists and go through this scientific process rather than trying to get at, Are they really getting any ideas out of it? Or are they really thinking about what they're doing? (Tape 91, p. 27)

Teacher Knowledge/Teacher Change

T1 emphasized the importance of supporting teachers in developing a variety of kinds of knowledge in order to create a conceptual change-oriented curriculum. He believed that some of this knowledge--about students' conceptions, about connections among concepts, about appropriate pedagogical strategies to promote conceptual change--could be built into curriculum materials. For example, he suggested that textbooks could pose more thought-provoking questions--"more the kinds of questions where you're asking kids what they think about so you can see what their misconceptions are and/or you can diagnose if they've really learned what I'm trying to get them to understand" (Tape 91, p. 13). He called for information in teachers' guides about the variety of kinds of responses that students might give, including information about common and important misconceptions. He suggested that textbooks could cover less content and explore concepts in more depth by presenting a variety of representations for a given concept.

But T1 emphasized that curriculum materials alone cannot make the difference. He clearly valued the professional development opportunities he had to focus on a unit during the summer--developing plans, teaching the unit, analyzing the unit, receiving coaching and feedback from peers and university experts. He suggested that all teachers need this kind of opportunity:

> One of the things about this kind of teaching, I think . . . it's hard to do it in just a teacher edition. I mean, you almost have to have a situation where you have teacher sit down for three or four days in the summer and go through how do you do this kind of questioning? What kinds of things do you look for, and even practice it. How do you stand in front of 25 kids and ask the right questions and hear all the different misconceptions and try to make a mental note of those so that you can come back to them? . . . So, to get teachers to teach that way, it's really tough to just do that in the margin of a teacher's edition. . . . I went through a four-week session with that, and you really would have to do that, and you would also need refreshers. (Tape 91, p. 33-34)

Thus, T1 acknowledges the complexity of teaching for conceptual change. He also recognizes that he is advocating a dramatic shift in the way elementary science is taught and in the way teachers are supported in changing their practice. He is not willing to abandon his ideals because of these difficulties. There are too many potential benefits for his students:

> You have six kids that all give these different ideas, and you want to pursue it with them and say, you know, really explore it with them and really what are they thinking and you know, am I just reading them wrong on their first statement, or do they really have this idea that this is what happens? So you go off on these avenues and by the time you look at the clock you've gone through 45 minutes and haven't even gotten the kids into groups yet or anything that you wanted to do. But you still, even with going over or not covering everything you want to, you still feel like you're doing a better job with the science because you still have the gains the kids are making and you still know that they can make discoveries and that they're understanding stuff a lot more, so it's not like sometimes you feel like, with reading, you're six stories behind and you're 17 skills behind and you've got to get all this done by the end of the year and you're rushing and rushing and then you get it done and you feel like half the kids don't understand what you were talking about anyway. (Tape 92, p. 3)

T2: Summary of Approach

Background and Overall Perspective

T2 has been a half-time science and math resource teacher in a small urban district in California for the last two years. In this role, he has taken leadership across seven elementary schools, two junior high schools, and the high school in developing an exemplary science program. This program development involved a review of programs across the country that have been identified as exemplary, collaboration with local teachers to develop new science goals, and selection of a new science textbook. In addition, T2 ran numerous workshops for teachers to model hands-on science teaching, helped teachers in grade-level teams develop model unit and lesson plans, acquired and catalogued activities and materials for teachers' reference, and did demonstration teaching in teachers' classrooms.

He received a half-time grant from the State of California Environmental Education program to develop a K-6 aquatic ecology curriculum. Part of this grant was used to construct a model stream/fish hatchery at one of the elementary schools and to produce an educational video to accompany the aquatic ecology curriculum. A major goal in this work has been to create enthusiasm among teachers for teaching science, and there is much evidence to point to success in this area. T2 sees his district as having coming a long way in the last two years but still being in the fledgling stage of moving from a reading comprehension science curriculum to a process-oriented curriculum.

T2 came to this position from a long-time interest and activity in science. He has bachelor's and master's degrees in fisheries biology and has been teaching for 12 years in Grades 4-8. His teaching experience began in two rural school districts; later he moved to the larger system where he now teaches fifth grade.

In addition to his leadership within the district, T2 has been active in state and national science organizations such as National Science Teachers Association and the California Science Teachers Association. He has worked on three state science committees--the framework committee in science, the model curriculum guidelines subcommittee, and the California Assessment Program committee. T2 has demonstrated a strong interest and leadership in science education within the state and the district. He is enthusiastic about turning on teachers and students to science.

T2 brings a process-focused, hands-on orientation to the elementary school science curriculum. He advocates process-oriented science in which a primary goal is the development of positive attitudes toward science by both teachers and students. To promote teacher enthusiasm for science he believes in involving teachers actively in curriculum development and in integrating science across the subject areas.

Goals of the Ideal Science Curriculum

T2 agrees with the curriculum goals we suggested that focus on balancing breadth with depth by addressing limited content. However, he does not advocate organizing the content around a limited number of key understandings and emphasizing the development of conceptual understandings as a primary goal of the elementary science curriculum. Instead, he added to our list of key features of the ideal science curriculum two central goals: (a) the development of positive attitudes toward science and the disposition to inquire and (b) the development of process skills. Content goals are secondary outgrowths of students' engagement in using and developing these attitudes and skills. The skills are useful to students across subject matter domains and thus are more critical than the development of content knowledge.

Attitudes. The first goal listed in the program goals document for his school district is to develop a positive attitude towards science. In his written response to our analysis task, T2 elaborated this as a primary goal to add to our list of key features of an ideal curriculum. He also emphasized a positive attitude must be a goal for everyone involved--administrators, teachers, parents, students. T2 is especially interested in developing a positive attitude in all elementary teachers toward science. This is a critical component because of the teacher's vital link in establishing this goal with children: "The teacher 'infects' the students with the opportunity to acquire knowledge and access and use it when needed" (Written response, p. 1).

T2 described some of the features of these attitudes in his interview:

> What I stress with the teachers . . . is you're modeling the inquisitiveness of the scientists. And that's one of the--besides the content areas and the process skills--attitudes is probably one of the biggest things that we try and develop in the kids. A good attitude towards wanting to ask questions and delve deeper that innate curiosity, and develop that. (Tape 82, p. 23)

> The disposition that we're looking for would be an inquiry-based disposition. One that they're inquisitive. They're positive towards solving a problem and delving into science and going through and identifying a problem. Going through and isolating the key elements of the problem and trying to understand how they're related and then seeing if they can solve that problem through these understandings. We're looking at an end result of an attitude that they succeeded through science and a positive attitude towards inquiry. (Tape 82, p. 26)

This emphasis on attitudes is reflected in the way T2 evaluates and grades his students in science:

> I've never really kept science grades per se from papers. I've always worked more on how much time the kids have put into it, how much involvement. . . . If the kids are really trying and their attitude really improves over the year, I give them the B's and A's in science because I really want to stimulate that. . . . And if they can get a B or an A in science, it might stimulate them to take another course in high school. (Tape 83, p. 3)

The kinds of attitudes T2 is working on go beyond attitudes toward science, however. He also views science as a vehicle for working on self-esteem and learning to work cooperatively with others:

> I use science as a really unifying part of the classroom, and when the kids can work together in small groups and I can break those groups up and they can work together in a new group, I know I have accomplished that. (Tape 83, p. 3)

Process skills. A second goal that T2 added to our list and emphasized throughout his interview was the development of process skills such as observing, comparing, classifying, measuring, graphing, applying, critical thinking, and so forth. He believes that science should have a primary focus on teaching "the process skills through developmental activities at appropriate levels" (Written response, p. 1). He describes this as a more efficient way to teach science: "Teaching science for the sake of inspiring students to develop these process skills. Critical thinking skills. 'Sciencing,' I guess, is what you'd call it. Becoming a scientist. Becoming a thinking person" (Tape 82, p. 10).

T2 sees content in a secondary, supportive role. He describes content as the "hook" or "springboard" to get students thinking and developing process skills. He also recommends depth versus breadth of content coverage because the content is only needed to serve the development of the process skills:

> Rather than cover a lot of subject matter, we are focusing on the science skills. On sciencing as a skill, rather than the content. I view it as using the content to hook the kids because it is interesting and developing process skills that can be used in problem solving. (Tape 82, p. 3)

T2 continues his rationale for a process-oriented curriculum by emphasizing the usefulness of sciencing skills in other subject areas:

> Developing process skills that can be used in problem solving and any other curricular areas as far as developing communication skills . . . skills that will be beneficial to them as a person, being able to solve problems and think logically. That's the main goal of the program. (Tape 82, p. 3)

It is here that T2 believes that teachers can see the real relevancy of science and science process skills:

> Once teachers realize that everything they use is there because of science and that everyone uses the process skills everyday that scientists use, the relevancy of science hits them in the face. Every basal reader is more than 50% science content. Math and science is the perfect fit. Social studies without science would be pretty dull. And where would language arts and the fine arts be without the scientific inspirations and inventions be? (Written response, p. 2)

Thus, T2 emphasizes integration across subject matter areas as another critical goal of science education that we left out of our list. He sees it as important because this is where students will use the process skills developed in science (relevance) and because such integration will contribute to teachers' enthusiasm and positive attitude toward science.

Nature of higher level thinking. Again, T2 maintains an emphasis on the science process skills. He describes higher level thinking as the science process skills such as observing, comparing, classifying, measuring, graphing, applying, critical thinking, and problem solving. He sees these as having wide applicability in and out of school. He does not emphasize particular skills but believes they are all important to develop.

We infer from T2's comments that he views content thinking as less difficult and secondary to process thinking. For example, he repeatedly refers to content learning as "retention" or "remembering." Students will learn the process skills through activities, and "the concepts taught during these activities are meaningfully understood and retained by the student for future access and use" (Written response, p. 2). Activities focused on process goals motivate kids to want to read

> and to dive into the content and they retain more than a memory-based program of paper and pencils and worksheets. . . . If the kids have a hands-on experience with a frog in the classroom and then they go back and start reading about it. It's gonna stick. They retain it. (Tape 82, p. 19)

This view of content learning is connected to his view of science as reading comprehension. T2 associates activities with process skills and reading with content learning. He reflects a view that process learning is more difficult to develop ("As far as assessing the process skills, you're going to see an increasing skill there. It's right over the year. In the [content] understandings, you can probably measure that within a shorter period of time" [Tape 82, p. 27]) and more useful ("The process skills learned are readily available for use throughout the subject areas and outside school" [Written response, p. 2]).

T2 communicates that assessment of these process skills is a subjective process:

> Pretty soon you have that feeling that they've picked up those skills. . . . Pretty soon you acquire a sense of, yeah, I am asking the right questions. I'm getting responses. The kids aren't answering in yes and no answers. They're answering in questions. Working in groups, the kids start picking up questioning techniques and listening to each other. Pretty soon you get a sense that the kids are learning how to compare and contrast and classify and their observation skills just keep improving. It happens over a long period of time. Nobody picks it up overnight. (Tape 82, p. 21)

His description also emphasizes the time it takes for this kind of thinking to develop in noticeable ways.

Assessment of content knowledge is more possible on paper-and-pencil measures but still is not easy. T2 uses games like Quizmo in which students make up questions about the factual content and vocabulary. Their questions are used in a competitive review game, and the teacher can assess improvement in students' answers to factual questions across several iterations of the game questions. T2 emphasizes assessing content knowledge through student presentations and verbalizations:

> Being able to explain it to another student, or we use cross-age tutors a lot. Being able to take the concepts they're learning

> and being able to go down to a lower grade level and teach that to a younger student would be a real good way of assessing it. (Tape 82, p. 28)

The K-6 Curriculum: Content Selection and Organization

Process for identifying content organization. T2 played a lead role in selecting and organizing the content for the elementary schools in his district, and he emphasized that it is important to look at the curriculum development process as well as the criteria used. T2 identified the process that his school district used as important in the successes that they have had in getting teachers to teach science more often and to use more activities.

The process began with a review of the Science Frameworks for California Public Schools (California State Department of Education, 1978) and the Science Framework Addendum (California State Department of Education, 1984). In addition T2 and colleagues reviewed the California Science Model Curriculum Guide (California State Department of Education, 1987). T2 was involved in creating the Model Curriculum Guide which he described as an activity guide to accompany the framework. The frameworks documents were not intended to prescribe a specific set or sequence of topics for school curricula. Rather, the documents described basic science concepts and skills important for scientific literacy. The documents emphasized that "the development of attitudes and values, rational thinking processes, and manipulative and communicative skills should take place in close association with the development of concepts" (California State Department of Education, 1984, p. 1).

The frameworks documents emphasize the development of science process skills and organize these in a hierarchy that matches Piagetian developmental stages (sensory motor, preconceptual, intuitive, concrete operational). The skills of observing, communicating, comparing and measuring, organizing and classifying are emphasized for Grades K-3. For Grades 3-6 the skill of

"relating" (formulating experimental hypotheses, controlling and manipulating variables, and experimenting) was added to the list of appropriate process skills. "Inferring" (synthesizing, analyzing, generalizing, predicting patterns, and formulating explanatory models) was a skill deemed appropriate for Grades 6-9. In Grades 9-12 the skill of "applying" was added to the list. This process skill includes problem solving and inventing.

The frameworks also organize science content in a hierarchical fashion by grade level. Grade levels K-3 addresses "static-organizational principles" which include statements of knowledge that help one to observe, communicate, compare and organize material objects in the universe. Examples for K-3 include the following:

> Life Science: All animals need food, water, and air and a place to live. (California State Department of Education, 1984, p. 28)
>
> Earth Science: Sea water is salty. Water in most lakes and rivers is not salty. (p. 57)
>
> Physical Science: Light comes from a variety of sources. The sun is the source of daylight. (p. 78)

Concepts appropriate for Grade levels 3-6 include "active-relational, interactive principles" and includes statements of knowledge about the interactions and interdependence of systems and objects:

> Life Science: An ecosystem consists of a community of living things interacting with each other and with they physical environment. (p. 39)
>
> Earth Science: The oceans have a great influence on climate. (p. 57)
>
> Physical Science: When light strikes an object, part of it is absorbed and changed to heat. (p. 79)

"Explanatory-predictive, theoretical principles" appropriate for Grades 6-9 are stated as explanations of phenomena through perceived changes in objects.

Finally, Grades 9-12 address "usable-applicational principles," emphasizing the use of information to obtain further knowledge.

T2 also led his district in a review of exemplary science programs identified by the National Science Teachers Association. Five programs were studied in detail, noting ways in which they matched or failed to match the California frameworks. T2 noted that all of these programs were characterized by an emphasis on process skills and hands-on activities.

The review of the California documents and the study of exemplary programs provided information that groups of teachers within the district used as guides in selecting and organizing the curriculum content and sequence. At this level, T2 emphasizes the teacher-directed nature of the process. Teachers negotiated for content at particular grade levels. T2 believes that it is important to give teachers a say in this process and to allow them much room to personalize the curriculum so that they can teach subjects that interest them and that they are knowledgeable about. This process encourages teachers to teach science. As T2 asserts, the content is simply the "hook" to get kids interested and involved in the scientific processes. Therefore, the particular content selected is of secondary importance as long as students receive a balance of life, earth, and physical sciences.

Content organization. Through this process T2's district identified between 5 unit topics (Grades 2 and 4) to 13 unit topics (Grade 5) per grade level. This was the core curriculum from which teachers could select. The goal was for each teacher to develop 4-6 quality units across the school year. Grade 2 topics were animal groups and dinosaurs in the life science block, weather in the earth science block, and sound and light in the physical science block. At the fifth-grade level, the teachers selected the following topics:

Life Science: Senses, bones/muscles, cells/simple organisms, plants, animals without backbones, animals with backbones

Earth Science: Oceanography, astronomy/sun, astronomy/moon, astronomy/planets, astronomy/stars

Physical Science: Electricity, magnetism, sound

T2 noted that the content was organized around topics rather than around key understandings or concepts such as those listed in the frameworks. In fact, T2 found our exercise of identifying key understandings related to ecosystems as difficult to do:

> It was difficult for me to write the key understandings because I hadn't really sat down and looked at it that way. . . . Rather than organizing by key understandings we were picking a program that was a dinosaur basically, and trying to get an activity-oriented program going without any key understanding background in our organization. (Tape 82, p. 5)

Within each of the topics selected, T2 worked with teachers to identify activities that would help students develop the process skills identified in the frameworks as appropriate for that grade level. Working with grade levels in teams, he helped teachers plan units and lessons that incorporated activities at least 50% of the time. Teachers had release time from teaching to attend these half-day workshop sessions throughout the school year. In this unit planning process, T2 focused on getting teachers involved and enthusiastic about teaching activity-based science. Secondarily, he worked with them on understanding the concepts that they were teaching in these units.

Criteria for content selection. What criteria did the teachers in this district use to select dinosaurs for second grade and plants for fifth grade? Clearly, the first criterion was the extent to which the program overall would match up to the California frameworks. But the frameworks left a much room for selection of content. T2 identified five important criteria that were used in the selection process.

First, what content did the different grade level teachers want to teach? T2 wanted to gain teachers' enthusiasm about teaching science and felt that it was critical that they have a say in the content selected. He wanted to see teachers teaching "five, six quality units over the year that they can feel good about" (Tape 82, p. 4). The content was not as important as the teachers' enthusiasm for the content; T2 argued that any content can be used to teach the important science process skills. T2's emphasis on "selling" science to teachers in selecting content is reflected in his comments during the interview:

> It came down to a negotiation between the teachers. The only way that it would be successful in the district would be to have the teachers buy into it. If the teachers don't feel comfortable teaching the unit they aren't going to teach anything. It did come down to negotiations and there were some teachers who wanted to teach their dinosaur unit in second grade and some wanted to teach it in third grade. So we threw in dinosaurs [in second grade in life science] and fossils in the earth sciences [in third grade]. (Tape 82, p. 10)

The second criterion was process skills and hands-on activities. Could the content be addressed through a number of different kinds of hands-on activities? Were these activities ones that would be concrete experiences for the children? Could activities that relate to children's experiences be developed using this content? For meeting this criterion he lauded a LifeLab program in Santa Cruz, California, in which a science program including life, physical, and earth science is based around a community garden. T2 described a number of different sources that he researched to find appropriate activities to accompany the topics selected for focus (Science Curriculum Improvement Study, Elementary Science Study, Project Wild, Science on a Shoestring, Activities for Integrating Math and Science, Task Oriented Physical Science).

The third criterion for selection was student interest. Since content was viewed as the "hook" to teach students science process skills, it was important that the content capture students' imaginations. Again, this criterion was

closely linked to activities. Could the content be addressed in activities that would engage the students' interest?

The fourth criterion was to select only a few topics for emphasis at each grade level. Using a "Little Steps Model," the district would select a few content areas at each grade level that would be taught as quality units (not as skimming the textbook). The selected topics needed to represent life, earth, and physical science at each grade level.

Finally, integration was a criterion. Did the content offer opportunities for integration across the subject matter areas? We list this as the last criterion because it did not seem to be a central criterion in the actual selection of content. Rather, there seemed to be an assumption that any content could be integrated in meaningful ways across the curriculum. Thus, while integration was an important goal of the curriculum, it did not seem to play a major role in that actual selection and sequencing of content across the grade levels.

Views of Science Teaching and Learning

T2 did not articulate a particular model of science teaching or a particular theoretical view of student learning. However, he clearly believes that students must be engaged in hands-on activities to get excited about and engaged in their learning. He views these activities as the hooks that will get students motivated to read from the textbook and other resources about the content of science. He contrasts this process-oriented view of science teaching with a reading comprehension approach.

T2 also described the ways that he envisioned activities in use in the ideal elementary science classroom. An ideal lesson might begin with the teacher identifying the topic of the day and eliciting students' preconceptions and misconceptions. These could be written down on a large sheet of butcher

paper. Next the students carry out an activity. After the activity they discuss whether that activity helped them look at the topic in new ways--comparing pre- and postideas. In future lessons, students might extend these ideas in a reading or writing lesson that would stress vocabulary development. A culminating lesson would review and summarize the content, perhaps using a Quizmo game in which students make up content questions about the topic and compete to answer the questions.

T2 mentioned the importance of teacher questioning in this way of teaching science, but he acknowledged that it was difficult to get good at this kind of questioning. He helps teachers in his district through demonstration teaching in their classrooms and observations of teachers. T2 described the questioning process as something that you gradually get a feel for; he did not specify particular characteristics of better and worse kinds of questions.

T2 emphasized the importance of cooperative learning strategies and a classroom climate in which students feel good about themselves as learners of science. He sees activity-oriented science teaching as promoting friendships and opening up lines of communication that benefit the classroom in more ways than just developing science understandings. It helps make "all of the little petty hassles vanish" (Tape 82, p. 18).

Teacher Learning and Curriculum

P2 identified inservice work with teachers as critical to supporting elementary science teaching. He advocates having science consulting teachers on school district staffs. These people would be teachers with strong backgrounds in science who can provide resources and support in teaching science. For example, in his own experience in this role he ran regular inservice workshops for teachers, supported teachers in the classroom, interacted with teachers in planning science lessons and units, and collected a resource library of

science activities and materials. He believes that this inservice time must be quality time--for example, a half-day per month over the school year.

A key to successful workshops is getting teachers involved in the activities, thus inspiring them to want to teach science. Raising their comfort level with doing science activities is more important than teaching them science content. The primary goal of inservice work should be to promote positive attitudes among teachers about teaching science. He viewed his role as science specialist as "selling" science. What will sell science to teachers is a good set of resources for manageable, highly motivating science activities. Support in planning the enactment of these activities is a critical focus of inservice time, with teachers working together in grade-level groups to plan science units.

P2 did not have as much to say about the role of curriculum materials in supporting teacher learning and teacher change. He was not critical of the SBG textbook series, seeing it as a good source of science activities. However, the curriculum materials that he thought were most critical for teachers were catalogues and reference notebooks identifying good science activities to do with elementary children. If the activities were catalogued and available in one place without lengthy searches, teachers would be more willing to try them. Thus, the key to teacher development in T2's view was getting them involved in science activities and supporting them in developing good feelings about science.

T3: Summary of Approach

Background and Overall Perspective

T3 is a first-grade teacher in New York state. She has 21 years of teaching experience; for 13 of those years she taught the lower elementary grades (K-2) and for 7 years she was a resource teacher for learning disabled

children. She holds a master's degree in early childhood development and pursued graduate studies beyond the master's to obtain certification in special education.

She has had a lifelong interest in science. Her father was a chemist, and T3 began her college career as a chemistry major. She has pursued this science interest through her teaching experience, taking a leadership role in her school and in the state in science education. She has taken advantage of numerous opportunities to extend her own science knowledge through graduate courses at Cornell University and State University of New York at Cortland as well as summer institutes such as the Elementary Science Institute at SUNY-Cortland. She was one of four central New York teachers who participated in a Support/Coach Teacher Leadership Training program in preparation for her role as coach teacher in training mentors and developing curriculum in schools in her state geographic region.

She also participated in an inservice conservation training workshop sponsored by the New York State Department of Environmental Conservation and the New York State Conservation Council. From 1986-1988 she worked closely with staff from Cornell University's arboretum to implement, evaluate, and revise science units about plants. Emphasis was on questioning techniques, classroom structuring of lessons, science subject matter knowledge development, and addressing students' misconceptions about plants while teaching sound science concepts.

T3 has been involved in curriculum development work in science. She was director and coordinator of a summer curriculum writing project which developed two comprehensive units in physical science (air and chemistry) for K-2, utilizing a spiraling hierarchy of concepts. She helped implement this curriculum in her school. She was consultant for a similar summer curriculum writing

project which developed two comprehensive units in physical science for Grades 3-4, a continuation of the conceptual spiral started in grades K-2. She received a minigrant to develop and implement an environmental curriculum in her school. In this project she worked with the Social Studies Program Coordinator to develop an integrated science and social studies curriculum within the school.

T3 has given papers at several conferences including the Science Teachers Association of New York State, the National Science Teachers Association, the United University Professions Task Force on Teacher Education, SUNY-Purchase Teacher Center's fifth annual conference, and a Teachers Teaching Teachers Conference. These presentations have focused on her work in integrating science with the language arts and social studies and her work as a coach science teacher. She received the 1988 Excellence in Science Teaching Award for the Elementary Level from the Science Teachers Association of New York State.

"How can you conserve what you don't understand? How can you be responsible for something if you don't understand the way it functions or the way it works?" (Tape 49, p. 22). These statements from T3 capture several important aspects of her perspective about the elementary science curriculum. T3 advocates a science program that develops "appreciation through understanding."

She believes that science instruction should focus on citizenship goals and encourage students to take action based on their knowledge. However, such action must be based on knowledge and understanding. T3 emphasizes four aspects of instruction that she believes support the development of meaningful understandings: (1) exploration of a few meaningful ideas in depth, (2) linkage of science study to real-life, local issues, (3) multiple exposures and approaches to the study of a few key science concepts across time, and (4)

integration of science study with social studies, language arts, and mathematics. Thus, T3 emphasizes an interdisciplinary immersion in the study of science concepts.

Goals of the Elementary Science Curriculum

Like the other experts, T3 agreed with the key features of the ideal science curriculum that we had suggested. However, T3 emphasized that the overall curriculum should be organized around a theme that ties the content studies directly to the students' real life environment. The theme that she had used with her first graders one year was We C.A.R.E.--We, the citizens of Thomasville Elementary School, C (Conservation)

A (Appreciation)

R (Responsibility)

E (Environment)!

This theme reflects T3's focus on the citizenship goals of science education:

> One of the goals of science teaching is to build a conceptual framework which will expand and develop with additional experiences upon which decisions regarding the quality of life can be based. We felt that there needed to be a way to involve our students beyond just the classroom or grade-level experiences. As growing citizens they should be using their science skills and knowledge to make a difference. (Written document #1, p. 1)

The We C.A.R.E. activities that T3 described reflect her goals of "citizenship through science" and integration of all subject area content and process skills. Throughout the year students studied science concepts--about living things, dependency of plants and animals on each other, niches, ecosystems, properties of matter, physical and chemical changes, temperature changes, states of matter--through a series of activities, projects, and environmental studies conducted on the school grounds. Students at different grade levels conducted niche watches, analyzed food webs and human impact on them, visited a

virgin forest, adopted and observed trees, measured trees and analyzed damage from insects or weather, studied decay and life cycles in fallen logs, analyzed trash, mapped trees, studied temperature patterns, conducted a decomposition observation post, and so forth.

Language arts activities embedded in these studies included writing in observation journals, writing letters to the editor of the local paper, publishing stories about appreciating the environment. Social studies goals were addressed through visits with local environmental engineers and conservation officers, a study of the history of trees in the town, and the development of recommendations for the local tree commission in planning for the future of trees in the area. Math activities included measurements and estimation of tree height, girth, and age as well as the construction and use of histograms to study temperature patterns and change across the school year. Thus, T3's view of depth over breadth included a critical citizen action component. Understanding science concepts was directly tied to problem solving and decision making as a citizen.

T3 also viewed depth as necessary in addressing multiple content area goals within the context of science study. Because science is engaging and interesting to young children, it is an ideal context in which to work on reading, writing, speaking, mathematical, and social science skills. In T3's first-grade classroom such an integrated unit might involve several months of instruction, with only four or five integrated science units being taught across the year. For example, during the previous year she taught four units--air, chemistry (mixtures and physical changes), seeds, and life cycles. T3 labels her approach "holistic teaching," in which science lessons provide multiple experiences that foster concept and skill development across subject matter areas.

"No unit ever really ends," said T3, and she frequently used the words "connected", "big picture," and "fits together." This terminology reflected her belief that students should be supported in developing connected understandings of science concepts over time. To develop understandings of relationships and functions rather than names and labels, students need repeated exposures and involvement with key ideas across the school year and across the elementary grades. To appreciate the notion of change over time, for example, T3 has her students study and predict temperature each day across the school year. This provides long-term data and experiences that can help young children grasp the concept of change and patterns of change across time. T3 advocates a spiraling curriculum to support students in this process. She does not want students to see science concepts as separate bits and pieces but as woven together like a tapestry.

Higher Level Thinking in the Ideal Curriculum

T3 did not describe her views of the ideal science curriculum in terms of higher order thinking. Instead, she emphasized "understanding" as a primary goal. Her vision of "understanding" included the abilities to apply knowledge, to solve problems, and to appreciate the natural world. She believes that such understandings will promote inquisitiveness and positive attitudes toward science. She views process skills as integrated pieces of scientific understanding; they develop in the context of concept study. Her notion that appreciation and awareness develop through understanding suggests that she may regard appreciation and citizen problem solving as the highest level thinking goals in her classroom.

The K-6 Curriculum: Content Selection and Organization

Criteria for selection. Two criteria for content selection stand out in T3's comments. First, content should be selected that will help students

develop deeper understandings of their real-world environment. Thus, content should be specific to the local district and personalized to the particular students in the class:

> We teach children so that they can apply it to the real world, and the real world has all these things around them all the time. So if you're a teacher who is responsive to what children are interested in, they are constantly bringing in these things or they are bringing them up or noticing things. (Tape 49, p. 11)

Thus, a key criterion is that the content be linked to the children's experience.

Secondly, the content should lend itself to integration in two ways: the linking of science concepts together over time and the linkages of science content with language arts, mathematics, and social studies content and skills. Content should be selected that provides opportunities for multiple linkages and that lays groundwork for future study at higher levels of abstraction and complexity.

Depth vs. breadth. T3 has a much more content-focused view of the curriculum than T2. She contrasted the large range of content covered in the SBG series with the units that she and her colleagues had been developing and using:

> They have enough stuff here [in SBG] so that you couldn't do it like we do, which would be to spend a month-and-a-half on air or something like that. (Tape 50, p. 2)

> When we put together our two big units, and they were in huge notebooks, to develop a good conceptual unit that you're going to teach really thoroughly and really integrate all areas of curriculum into. . . . You could spend several months just on one unit, and you may not, when you're starting a science program in school, you may not get through more than four or five units in a year . . . because you're going through the whole process of thoroughly teaching it. (Tape 49, p. 15)

In addition to T3's emphasis on covering limited content in depth is her emphasis on the idea that "no unit ever ends." Thus, depth of instruction

includes revisiting key ideas in new contexts across a school year or ideally across grade levels:

> You don't just hit kids with a concept at some higher level and expect them to understand the concept or understand the value of the methods you use to gather the information. You can build that throughout their school career. (Tape 49, p. 5)

Content integration within and across grade levels. T3 advocates a spiraling curriculum both within and across grade levels. When she is teaching her first graders about seeds, for example, she uses a variety of approaches to help students understand that food is stored in the seed. "Now the children can't really understand why the food is there, but they eat seeds, animals eat seeds. They have food for us. Okay, so that's one little groundwork that you've laid for the idea that plants make food" (Tape 49, p. 6). She views photosynthesis as a more complex understanding that can be taught later, perhaps in fourth or fifth grade. At that time, students can revisit the idea of food stored in seeds in the context of new ideas about photosynthesis. T3 also does not believe in teaching separate science units across the year. Her unit on air is related to her units on seeds and life cycles:

> Teachers frequently wonder, why are we teaching about air? Why are we teaching about water? Why do we teach about, you know, energy from the sun? They're all related. They have . . . the sun is the cause of the plants being able to make the food. The sun causes changes that occur in air, temperature, and consequently air pressure, et cetera. The energy of the sun is vital to our Earth. (Tape 49, p. 2)

T3's first-grade science curriculum illustrates how she emphasizes how connections among science units and activities. One example is the daily temperature work done by her first graders. As part of the morning routine (not the officially designated science time), students make predictions about the temperature of the day. They then compare their predictions with the actual temperature and discuss ways to make accurate predictions. They create

histograms showing temperature patterns, and they write in their journals about their observations and predictions. Across the year, T3 ties this work into students' studies of plants and seeds, air, life cycles, weather, and change over time.

T3 charted a plan of how concepts might be approached in a spiral fashion over the elementary grade levels. In her model, science concepts can be organized in a hierarchy of sequential understandings necessary to develop higher concepts. For example, Table 3 shows how she represents the differentiation of living versus nonliving things as a basic concept that needs to be understood before the concepts of community or ecosystem can be taught. Her chart illustrates how concepts can be approached for different purposes at different grade levels. Some ideas are merely mentioned at one grade level but are later explicitly taught.

After ideas are explicitly taught, they are revisited several times in new contexts for reinforcement and increased depth of study. Notice that T3 recognizes the need for concepts to be explicitly taught more than once across the K-6 span. For example, food chains might come up in the context of first-grade studies of adaptations, then be explicitly taught in both second and third grades, and then be reinforced in later grades in the context of studying ecosystems and changes in ecosystems. Although T3 represents this content in what may appear like a developmental hierarchy, she firmly believes that "nothing is for one age group exclusively."

Views of Science Teaching and Learning

Two themes emerged from T3's descriptions of ideal science teaching and learning: the importance of connections and learning by doing. T3 had put these two ideas together to serve as a very broad framework for her thinking about instruction. She did not have an explicit instructional model for

Table 3

Life Science Understanding:
Curriculum Emphasis Across K-6 Grades

Understandings	I Developing an understanding of how living things interact with each other and with their physical environment.						
man & ecosystem	✳	✳	✳	✳	□	□	□
changes in ecosystem		✳	✳	□	□	□	□
ecosystem	✳	✳	✳	✳	□	□	□
environmental conditions	✳	□	□	□	○	○	○
population	✳	✳	✳	□	□	□	□
food web	✳	✳	✳	□	□	○	○
food chain	✳	✳	□	□	○	○	○
niche	✳	□	□	○	○	○	○
community	✳	✳	□	□	○	○	○
adaptations	✳	□	□	○	○	○	○
habitat	□	□	○	○	○	○	○
living things	□	□	○	○	○	○	○
GRADE LEVEL	Kdg.	1st	2nd	3rd	4th	5th	6th

✳ = Touch on lightly in context of other lessons to lay groundwork and vocabulary awareness for later introduction of concept. Build experiences!

□ = Introduce concept and teach.

○ = Reinforce and/or review from previous teaching.

science, but did refer often to this "framework" (Tape 49, p. 5). This framework had at its core the "big picture" (p. 10) of the science concepts and how students might develop increasingly complex understandings of these concepts across the K-12 span. Tied to this big picture or "concept map" were experiences that would help children come to understand. It is the teacher's role to have the conceptual big picture and to provide enough experiences to help the students begin to understand some of the connections and big ideas.

"Experiences" rather than "activities" probably captures better what T3 meant by "learning by doing." Certainly, hands-on, concrete activities was one kind of experience that T3 was including in "learning by doing." In her written response, she talks about "allowing children to discover, manipulate, and thereby internalize their own understandings of the natural world" (p. 19) using concrete experiences whenever possible. Such hands-on experiences can lead students to discovering: "I know because I did it, I tried it out." However, T3 emphasizes a variety of kinds of experiences including cognitive engagement in writing, reading, and discussing ideas. In her classroom, journal writing and cooperative learning groups in science are two ongoing experiences that T3 believes are critical supports to students' learning and understanding.

Another key piece of T3's instructional framework is the importance of multiple exposures and experiences with a given concept. "Multiple exposures to a concept both within the individual classroom and throughout the spiral of the curriculum is essential" (Written response, p. 1). She used the example of how a nonreader was able to make a useful comparison between bean life cycles and meal worms because of the many experiences he had in science related to plant life cycles: reading a book, growing seeds, studying withered vines of pumpkins, collecting the pods on morning glories, and so forth. These experiences

are also essential across the grade levels in T3's view. She believes that early experiences contribute to both understanding and awareness. Awareness is a necessary precursor for future understanding; and developing understanding increases awareness and appreciation:

> Decay and natural recycling can be observed by children of all ages. Even first graders can feel the warmth in a bag of decomposing organic matter as it releases heat in a chemical process. Some of them know compost piles heat up. The natural world provides us with a bombardment of experiences [emphasis added], some of which we understand, some of which we only become aware of; that awareness is stored as groundwork for later concepts. (Written response, p. 17)

T3 views science as a natural place to develop students' language arts skills, including writing, vocabulary development, and reading. Students' daily journal writing and her responses to the children's writing often focus on science observations and questions. Groups of students take turns being responsible for recording observations and conclusions in a class "Science Journal." They are also responsible for reporting to the whole class about their observations and findings. Science words are the natural choices for reading and spelling work. Building on her whole-language approach, she ties science and language arts together as "natural partners."

T3 views these writing, drawing, discussing, and other language arts experiences as critical assessment tools for the teacher. The students can be writing and drawing instead of completing mindless worksheets for their seat-work while the teacher is working with a reading group. "This is meaningful work. The writing is very important and . . . the drawings are really important because they are a way to evaluate what the kids are really thinking" (Tape 50, p. 6). T3 then told the story of a first-grade girl who was brainstorming with drawings about things she knew about plants. From her continual use of plants in pots, T3 learned a lot about this students' conception of

"plant." She also believes that student group work and presentations can provide critical assessment of student learning. In her classroom, first graders plan and "teach" science lessons to other classes and to parents.

Teacher Learning and Professional Development

T3 valued a series of professional development opportunities which had helped her improve her science teaching. She was clearly drawing from these experiences in making recommendations about the kinds of professional support and development opportunities that would improve elementary science teaching. The critical pieces of support for inservice teachers that T3 recommended were: (a) attention to teachers' knowledge of science and support in identifying key concepts and why they are important to teach and (b) restructured teacher time and roles to enable teachers to interact with other professionals about science teaching and learning on a regular basis.

T3 thought that course work in science could be helpful for many teachers, but she did not view such course work as addressing a major science knowledge need. That need is to see the "big picture," to see how the tapestry of science weaves together, how science concepts fit together. T3 believed it was particularly important for elementary teachers to develop such a view. "A common lack of understanding is 'Why are we teaching this? What are the links--the connections?'" Teachers need a holistic understanding of science in order to make good instructional decisions in science and to integrate science in meaningful ways with other subject matters. School districts might hire people to help teachers see the big picture, or teachers might have release time to explore science with local university researchers or with other teachers.

How can teachers be supported in developing this kind of knowledge? T3 suggests a few ways that textbooks like SBG could do a better job of supporting

teachers. For example, teacher's guides could do a better job of emphasizing links among topics and concepts within and across grade levels. In addition, textbooks could provide more help with questioning strategies. T3 suggested that instead of just saying in the introduction that teachers should use writing logs and cooperative groups, they should develop at least one unit that provides explicit support to teachers in using such teaching strategies.

However, T3 acknowledges that such supports from a text are not sufficient. It is critical that teachers have meaningful opportunities to learn by talking things through:

> I think you need to also do a lot of discussion with other people about their views of teaching and their views of how things fit together. I think you learn best by talking things through. . . . [The project she worked on] really has been trying to provide that for us. Each time we've gotten ready to pilot a new unit, we would have a workshop a half a day or something where we'd all get together. They'd talk about what they were focusing on in the unit, and we'd discuss how, you know, what we felt we had needs in terms of understanding certain things and then after they were finished, after lessons were finished, we'd spend time discussing that as well. That's the kind of thing that a textbook can't provide. (Tape 49, p. 12)

Another form of inservice support that T3 advocated was teacher coaches who could work right in the classroom with teachers, providing teaching support and feedback. She stressed that support needs to be provided over a long-term period such as three years for it to be meaningful.

T3 recognizes that it is not "comfortable or natural" for schools to provide this kind of long-term support for teachers:

> They feel that you're in there, and you're teaching every single day. It's kind of a new idea for them to provide release time where you can actually have time to get new information, look at it, and then let it kind of jell. And it has to continue on a long-term basis. (Tape 49, p. 13)

However, T3 is also convinced that such opportunities can enable teachers to become comfortable and effective with their science teaching. In some of her work beyond her school, she herself has acted as a coach/support teacher and would like to see more of this kind of inservice teacher work.

Comparisons Among the Three Teacher Experts

The three teachers each emphasized different goals of elementary science instruction, with T1 focusing on the development of conceptual understanding, T2 emphasizing the development of science process skills and positive attitudes toward science, and T3 emphasizing the citizenship goals of science education. In this vein, T1 wanted students to understand important concepts about light and shadows while T2 would have been more interested in students being involved in making predictions about light and shadows, checking out their predictions, and enjoying the doing of science. T3 wants students to use their understandings (about temperature, air, seeds, plants) to act in a caring and thoughtful way in their environment. Both T2 and T3 separated goals into science content, science process, and science values and attitudes. In contrast, T1 saw process and attitude goals as much more integrated with and an outgrowth of teaching for conceptual understanding.

The teachers can be placed along a continuum with regard to their ideas about what should dictate content selection and organization. At one end of the continuum would be T1, who would select meaningful science concepts that students at the target grade level can come to understand in meaningful ways. Thus, his emphasis would be on the science disciplines (What are important concepts in science?) and on children (How do kids think about this concept? Is it something they can come to understand in deeper ways?). He would not advocate teaching about dinosaurs just because kids are fascinated with them.

He would rather eliminate the chapter in the SBG text about dinosaurs than leave it in without any major concepts being developed from it.

At the other end of the continuum would be T2, who would select content based largely on teacher and student interest. In his district, he responded to teacher and student interest by devising a way to include dinosaurs in the district curriculum at two different grade levels. His focus was on interest and on getting science taught; the particular science concepts that were taught about dinosaurs were not a major concern for him. In the middle of the continuum is T3 who valued both the selection of important disciplinary concepts as organizers for the curriculum and the selection of topics that will be captivating for students and not too intimidating for teachers.

The teachers also varied in the extent to which they had an explicit theoretical stance or instructional model. Again, T1 would be at one end of the curriculum with a strikingly focused conceptual change orientation to thinking about student learning and science instruction. At the opposite end of the continuum would be T2 who did not articulate an explicit theory of student learning or an explicit instructional model. His approach seemed to be much more affective and inspirational in nature. In the middle, T3 had a clear focus on the development of conceptual understanding and some well developed positions about the role of writing in science instruction and about the integration of language arts and science in young students' learning. In contrast with T1, however, her theories and models seemed to describe her teaching but not to drive her teaching: that is, she did not have an explicit model that guided her daily instructional decision-making; rather, she had a broad framework that guided her overall planning and teaching.

The teachers had different ways of analyzing and using activities in the science classroom. T1 was quite selective in the activities he used in his

light and shadows unit, emphasizing the importance of activities and the questions framing them in helping students change their naive conceptions to more scientifically appropriate ones. He also emphasized student and teacher writing as an important part of science activities; such writing helped both students and teacher reflect on activities and integrate ideas. T3 had a similar emphasis on selecting activities that would support students' conceptual development. She, too, advocated student journal writing in science but in her view the science journal writing was just as much a part of the language arts curriculum as it was part of science. T2 was focused on the motivational aspects of activities and on the "hands-on" aspect of activities. As he critiqued the activities in the SBG text, it was usually an analysis of the activity in isolation--its manageability and its potential to get students and teachers excited and involved. In contrast, both T1 and T3 analyzed the activities in the text in terms of how they connected to concepts being developed.

What does it take to support elementary teachers in teaching science? All three teachers pointed to the kinds of professional development activities they had participated in as necessary for all teachers. The three teachers were each involved in special professional projects not typically available to the classroom teacher. The teachers supported regular and frequent inservice time structured in ways that would enable teachers to work with each other and with outside experts (from the research community or a support science teacher) supporting and guiding their work. This support would include in-the-classroom coaching and possibly coteaching. T1 emphasized the knowledge demands that "this kind of science teaching" puts on teachers, while T2 down-played the knowledge aspects of successful science teaching.

None of the three teachers felt that a text like SBG would play a significant role in supporting teachers who are uncomfortable with science. T1 was the most critical of the textbook, and he was the only teacher who was using a textbook on a regular basis in his classroom. It may have been his use of a text and the ways in which it contrasts with his conceptual change unit on light and shadows that made more obvious to him the traps the text creates for teachers and students. All three teachers recognized the superficial attempt of the text series to address the idea of learning logs and cooperative learning. In such logs students write about their thinking in response to classroom activities; the emphasis is on the quality of their thinking rather than right answers. They felt that the text series could do a much better job of supporting teachers in learning about student thinking and misconceptions and in implementing regularly such teaching strategies as journal writing and cooperative learning.

Comparisons Between the University-Based Experts and the Teacher Experts

An obvious and expected difference between the university-based experts and the teacher experts is the degree to which they draw from research to develop explicit theories and models. The university experts were much more prone to this, and the teachers commented that participation in this research project was one of the rare occasions on which they were asked to articulate and defend their positions and philosophies. It is interesting, however, that two of the teachers had quite well developed theoretical positions, and that both of these teachers had been involved in professional development activities in which they interacted significantly with university professors. The development of an explicit theoretical stance in his interactions with university researchers seemed to have been a key piece in changing T1's approach to science planning

and teaching. For T3, the interactions with university experts did not have such a dramatic impact on her actual teaching practice, but it seemed to help her be able to describe her practice in more theoretical and integrated ways.

A striking difference between the teacher group and the university expert group was in their ways of thinking about what is needed for supporting teachers in elementary science instruction. The three university experts, while concerned with inservice and preservice teacher education, focused on the role of curriculum development and curriculum materials in supporting science teaching. In contrast, the teachers focused on inservice teacher development opportunities and the need for quality time and expert support to plan, teach, and study science units.

Overall, we were impressed that the areas of consensus and disagreement did not fall into university- and teacher-camps. Therefore, we focused our major analysis across the six experts: What were ideas that were generally shared across the experts? Where were there differences of opinion and why?

Discussion: Areas of Consensus

Features and Goals of the Ideal Curriculum

Given that our experts had been selected to represent different perspectives on the elementary science curriculum, we were struck by the many areas of consensus among them. With minor exceptions, the experts all began by supporting the features of ideal curricula that we had suggested:

a. Balancing breadth with depth by addressing limited content, but developing it sufficiently to ensure conceptual understanding;
b. Organizing the content around a limited number of powerful ideas (basic understandings and principles rooted in the disciplines);
c. Emphasizing the relationships among powerful ideas, both by contrasting along common dimensions and integrating across dimensions, so as to produce knowledge structures that are cohesive;

d. Providing students not only with instruction but also with opportunities to actively process information and construct meaning;
e. Fostering problem solving and other higher order thinking skills in the context of knowledge application; thus, the focus is less on thinking processes per se, and more on how to use acquired knowledge in new contexts.

All of the experts emphasized exploring ideas in depth instead of superficial coverage of many topics. They also agreed that science curriculum should emphasize big ideas rather than the development of detailed facts and vocabulary. Each expert stressed the importance of the development of connected understandings; they criticized typical science instruction as communicating to children that science is a bunch of isolated bits of knowledge. We were surprised by the extent to which all three university experts emphasized constructivist, conceptual change views of the learner. All of the teacher experts advocated active involvement of students in constructing meaning, although they were less explicit about their theoretical views of learning.

All six experts emphasized knowledge application as a critical goal of science education. Five of the experts viewed problem solving or conceptual understanding as the kinds of higher level thinking that students should be developing and applying to real-world natural phenomena. One teacher expert had a different view of higher order thinking, emphasizing the science process skills as primary goals of elementary science instruction. His view differed from the other experts who saw process skills as developing within the context of conceptual development.

Content Selection and Organization

One enduring problem in constructing science curricula is content selection and organization. How should content be selected and organized? Science includes content from many diverse disciplines (biology, physics, chemistry,

geology, and so forth), and the body of knowledge is large and continually growing. What is most important for elementary students to study? The experts shared a view that in many ways the selection of content is arbitrary. They argued for selecting content that students could come to understand in meaningful ways. Thus, they were not as concerned about <u>what</u> content was learned but that <u>some</u> content was learned in depth. As a result of this approach, students would come to understand what it means to "know" in science and would be able to approach new science learning by asking the right kinds of questions. By coming to understand at least some areas of science well, students would develop scientific habits of mind and dispositions to inquire, to make sense, to puzzle through problems.

The experts agreed on some of the criteria that should guide content selection. For example, the experts were unanimous in emphasizing usefulness of the science concepts in students' everyday lives as a critical criterion for content selection. Thus, concepts to be emphasized should not be selected only because of their importance within the science disciplines. The experts ranged along a continuum in terms of the balance of emphasis on the disciplines as a source to guide concept selection and on the relevance of the concepts to students' everyday experiences. P1, for example, seemed to place equal emphasis on both, while P3, the curriculum developer, placed more emphasis on content that addressed students' personal and social needs.

Connectedness was another criterion that the experts agreed was critical. Whatever content is selected, concepts should be developed and built upon over time so that students are given opportunities to connect ideas together. The experts were generally critical of the typical topics-centered approach in the elementary curriculum, where students study plants in one unit and then study rocks and electricity without any links among the units.

The experts also suggested that children's thinking should be an important criterion in content selection. What concepts are first graders or fifth graders capable of understanding in meaningful ways? Some of the experts advocated the use of research on students' conceptions of the natural world as a key source of information about content selection. They advocated selecting content that poses critical problems for children and that will enable children to make significant changes in their ways of understanding the world. Others emphasized the Piagetian developmental stages as an important source of information about what concepts children can understand.

The experts felt that activities and/or representations should also be an important criterion in content selection. Concepts selected for study in the elementary grades should be able to be represented in a variety of ways, including physical as well as conceptual representations. Content that cannot be represented for young children in multiple ways is probably not appropriate content for them.

A final criterion that the experts generally emphasized was teacher interest and teacher knowledge. Because they viewed content selection as somewhat arbitrary and because they recognized the typical elementary school teacher's lack of interest and background in science, the experts recommended that teachers have some voice in choosing what content will be addressed. We were surprised by the degree of consensus on this criterion; we expected that university experts would be more bound to the disciplines and less willing to let teachers' interests dictate the elementary curriculum.

The experts were in general agreement that content should be integrated and connected within grade levels. They differed in the extent to which they thought that integration should cut across different subject matter areas. They were also in less agreement about content organization across the grade

levels. Several of the experts proposed a spiraling curriculum, in which key ideas are revisited across the grade levels but are addressed in increasingly complex and abstract ways. Others were less convinced that such a spiral was a realistic goal for the elementary science curriculum. Teachers talked about the problems of a mobile population of students. One university expert felt that integration within a grade level was a more feasible goal and was willing not to worry about integration across grade levels.

Views of Teaching and Learning

Two of the university experts articulated instructional models. P1's model was clearly based on a conceptual change view of the learner. P3's model was more eclectic in nature, building on a variety of kinds of research on student learning including constructivism, conceptual change, Piagetian developmental studies, motivation studies, and learning styles research. The other experts did not have a specific model guiding their views of teaching and learning. However, all of the experts shared at least implicitly certain views of the learner and of instruction.

All of the experts, for example, believed that children's explanations of the natural world should serve as an important foundation for instruction. Instruction should challenge students' personal theories and help them develop more scientifically appropriate explanations. Most of the experts proposed eliciting students' ideas during discussion as a place to start instruction. They emphasized the importance of activities and problems that would pose discrepant events for children. The experts differed in the degree to which their views of teaching and learning centered around these ideas or were more eclectic in nature. For example, these ideas were the core of P1 and T1's approaches. They were simply one of several ideas forming the basis of P3's model and the approaches suggested by T2.

The experts all believed that hands-on activities should be a part of science instruction. They differed in their views of the role of such activities and in the teacher's role in guiding such activities. Some experts believed that physical manipulation of materials by students would help them discover and internalize science concepts. Others were less optimistic about the role of activities. They believed that the discourse surrounding the activities was more important in supporting student learning than the activity itself. Thus, they advocated careful selection of activities that would engage and challenge students' thinking. Other experts, particularly two of the teacher experts, placed more emphasis on the importance of including many different kinds of activities.

The experts were in agreement that new ways of assessing student learning were needed. They all criticized typical standardized tests and textbook tests that are primarily multiple choice, fill-in-the-blank questions about science facts. The most frequently mentioned alternative method of assessment was student writing. The experts mentioned learning logs as one rich way of tracking student thinking and development across time.

Teacher Education and Teacher Change

Not surprisingly, the experts agreed that elementary teachers need better support in developing their subject matter knowledge in science. They agreed that teacher development work must include thoughtful study of subject matter as a key component. The participants also recognized that curriculum materials would not be sufficient to support teachers in changing their science teaching practice and in developing appropriate subject matter knowledge. In addition, teachers need to be helped in becoming comfortable with science concepts and in developing new views of science teaching and learning. The experts had a

variety of ideas about the ways in which teachers need to be supported in making these changes.

Curriculum Development

The experts each asserted that it would require a great deal of teacher knowledge and adaptation to use existing textbook series in ways that will help students develop deep understandings of subject matter. Because they are aware that most elementary teachers lack such knowledge, the experts believed that improved science curriculum materials is a need at the elementary level. The experts had a variety of ideas about how curriculum materials could better support teachers in teaching for understanding. They also differed in how they thought the curriculum development process should proceed. However, they agreed that new visions of curriculum materials are needed. A point of agreement was the necessity to cut down on the amount of content and vocabulary in most science texts. The experts also agreed that texts could do a better job of helping teachers and students make connections and "see the big picture," as T3 explained. Finally most of the experts suggested that the teacher's guide could provide more information about common student misconceptions and the ways in which these misconceptions might influence students' responses to instruction.

Discussion: Areas of Disagreement

Features and Goals of the Ideal Curriculum

Certain features and goals of the ideal curriculum were suggested by individual experts but were not commonly emphasized across the group. For example, two experts (P3 and T3) emphasized personal and social goals that they described as citizenship goals. These goals included learning to work cooperatively in groups, learning to make personal and social decisions, and

developing self-esteem. Such goals are typically part of the social studies curriculum, but these experts saw them as a crucial goal of science education.

P3 emphasized both technology and health as important goals of the elementary science curriculum. He believed that science should not just be limited to disciplinary views of science but should be connected to social issues in children's worlds. He views health as a critical social issue for children and therefore a justified part of the elementary science curriculum. He emphasizes the importance of helping students understand technology because it is such an increasingly important and dominant feature of our society. Children should learn about the relationships between science and technology and the impact that each has on society.

P1 and P2 emphasized the development of self-regulation skills as an important goal of elementary science instruction. P1, for example, articulated two primary goals of elementary science: To help students develop conceptual understandings of science and to help students develop strategies for self-regulated problem solving. Both of these goals must be achieved, he argued, to enable scientific literacy in real-world, out-of-classroom situations. The features of self-regulated learning he describes include (a) evaluation of the compatibility between prior concepts and new information that is encountered, (b) decisions about whether the strategy being pursued will lead to an appropriate solution, and (c) determination of when an appropriate solution has been achieved. These skills need to be explicitly taught in the science curriculum according to P1 and P2.

The experts differed in their views of the relationships among science content goals, process goals, and disposition or attitude goals. Several experts viewed process skills as developing within the context of teaching for conceptual understanding. However, P2 and T2 advocated explicit teaching of

science process skills. They viewed science concepts and science processes as related but separate goals. Similarly, most experts viewed scientific dispositions to inquire and make sense as growing out of the development of meaningful conceptual understandings. T2, however, saw dispositions not as a secondary outgrowth but as a primary goal in itself. He wanted both teachers and students to like science and advocated "fun" activities as an entry point to developing such dispositions. He viewed scientific understandings as something that would begin to grow once these positive attitudes were in place. Thus, he viewed conceptual understanding as a secondary outgrowth of positive attitudes toward science.

The experts varied in the extent to which they viewed integration across the grade levels and across subject matters as important goals in science education. P1 argued that it was difficult enough to help students develop coherent, connected, and useful understandings of science concepts within a grade level. He thought it was unrealistic to expect elementary teachers to make meaningful connections across grade levels and across subject matter areas. That just makes an already complex task impossibly complex.

P3, T2, and T3, in contrast, were strong advocates of both kinds of integration. They were especially articulate in talking about integration across subject matter areas with links to the language arts and the social studies being more prominent in their discussions than links to mathematics or the arts. The early childhood expert, for example, saw rich opportunities for the development of language, reading, and writing through science activities. Similarly, P3 and T2 emphasized the contribution of the science education to important social studies goals. By linking science to social studies, they argued, students can be supported in linking science to their real world. It brings science down to a human, personal level.

Content Selection and Organization

There were several criteria suggested for content selection that were not shared among the group of experts. P1 and T1, for example, suggested that careful research on students' conceptions could serve as a critical criterion for content selection. Thus, experts could identify common student misconceptions about a variety of concepts and those could be used to select and organize content. What ideas do students typically have difficulty with at the first- or second-grade level? Can students at this age make some significant conceptual changes in those ideas?

Some experts were more bound than others to the necessity of balancing content from the life, earth, and physical sciences. The teachers generally assumed this guideline while the university experts had new ways of envisioning "balance." For example, P3 proposed a new balance among science, health, and technology.

Two of the teacher experts used state guidelines and exemplary programs in identifying the features of an ideal curriculum. Both T2 and T3 come from states with strong state-level leadership in education, and they both accepted their state-level guidelines. They used these guidelines in their local curriculum development work.

T2 (and to some extent P2 and T3) believed that science process skills should be a key criterion in selecting and organizing content. He advocated explicit teaching of the process skills (predicting, hypothesizing, inferring, designing experiments, controlling variables, and so forth). Therefore, these skills should be selected for emphasis in appropriate places in the elementary curriculum.

He also was a strong advocate for considering student interest in content selection. Others talked less about student interest directly, although

something like student interest was being considered in the recommendation for relevance to children's everyday life. "Engaging" students in a problem that was discussed by both P1 and P3 also seems relevant to interest. Certainly, the problem must catch students' interest to be "engaging." However, T2 seemed to mean something different than relevance or intellectual engagement when he talked about student interest. For example, he talked about dinosaurs in second or third grades. Dinosaurs are not exactly relevant to everyday life, but they are captivating to young children. T2 was more supportive of teaching about fascinating oddities of science than were the other experts because that met his criterion of student interest.

T2 also had a different way of thinking about activities as a criterion for content selection. In some respects, T3 shared his view that one begin with activities as an approach to content organization. T2 was a phenomenal collector of classroom science activities. He had notebooks full of them available for teachers in his district. He is a master at identifying activities from different programs and cataloguing them for his teachers. In working to support elementary teachers to teach more science, T2 begins with hands-on activities as a way to hook both teachers and students. Thus, he is satisfied with units the teacher teams develop as long as they include some activities in them. If the teachers can manage the activities and feel successful in using them, then maybe they will get intrigued with teaching science and eventually will focus more on the understandings instead of just the activities. The other experts had more demanding criteria for "good" activities. They viewed activities as worthless unless they fostered conceptual growth. In this vein, P2 advocated "minds-on" instead of "hands-on" activities.

Finally, the experts varied in the degree to which "integration" was a criterion for content selection and organization. While all agreed that

content should be integrated within grade levels, there were differing commitments to integration across grade levels and across subject matters. T2 was committed to life, earth, and physical science units at each grade level. The units were topically organized (astronomy, dinosaurs, plants, rocks, electricity, and so forth) and did not emphasize conceptual links. In contrast, T3 emphasized a spiraling of opportunities for children to interact with central concepts both within and across grade levels. She emphasized that "units never end." She suggested that students will develop different levels of understanding each time they encounter the same concept--first there is simply awareness, next conceptual understanding, and then further extension and application of the conceptual understanding (reinforcement). P3 also felt it was important to look across grade levels and think about developmentally appropriate concepts and skills for each grade level. However, like the other university-based experts, he did not talk much about the coherence of the curriculum across grade levels.

Even those experts who advocated integration across subject matters only occasionally identified this kind of integration as a criterion for selecting content. Rather, they identified most science content as having a variety of possibilities for links to other subject matters. One exception to this was P3's insistence that the organizing concepts (key ideas) of the science curriculum be abstract enough that they are <u>not unique</u> to science but can apply equally well to health, technology, and other domains. Thus, ideas like change and order are useful across domains while ideas like photosynthesis and kinetic molecular theory are too specific to science. Another exception is P3's and T3's emphasis on citizenship goals and links to science. This carries with it the implication that societal issues related to science will be emphasized--ideas like pollution, nuclear power, acid rain, endangered species, and so

forth In contrast, T1 omitted ideas about pollution from his suggested ecosystem lessons because he felt that students put too much emphasis on humans in the ecosystem. He wanted them to see humans as just one part of the ecosystem and not to view ecosystems as existing for the benefit of humans.

Views of Teaching and Learning

P1 and T1 shared a focused theoretical perspective on student learning. They were both thinking hard about the implications of studies of students' misconceptions for curriculum development and classroom instruction. They characterized their views of having a conceptual change orientation. In contrast, P2 and P3 were drawing from this conceptual change research base as well as from a variety of other research traditions (motivation, learning styles, developmental stages, constructivism, health education, and so forth) to form a more eclectic and multifaceted view of the learner. As a result of their less-focused view of the learner, their instructional models and suggestions for teaching are broader and more generic in the sense of being applicable across subject matter areas. T2 and T3 had not articulated a particular instructional model, although it is clear that they each had identified certain key components of instruction.

P1's conceptual change model of science instruction calls first for engaging students in a compelling problem or question. This phase of instruction includes eliciting students' ideas about some natural phenomena, challenging students' ideas through discrepant events, and presenting scientific explanations in contrast with students' personal theories. The second phase of instruction provides numerous opportunities for students to try using the new concepts to explain a variety of real-world, everyday phenomena. During this phase of instruction the teacher models explanations and learning strategies

and coaches students in using similar strategies. Finally, teacher scaffolding fades as students engage in much more open-ended problem-solving activities.

P3 describes his instructional model as a generic conceptual change model, and in many senses that is just what it is. The model consists of five e's: engagement (student interest), exploration (through hands-on activities), explanation (the scientific concepts), elaboration (extend and apply), and evaluation (students and teachers assess progress). In comparing curriculum materials designed by P1 and P3, it is clear that P1 views the application phase to be much more extensive and sees the teacher as playing a much more central role as cognitive coach in this phase. Thus, as students attempt to work with new ideas, the teacher needs to be coaching the students in attempts to use the ideas. P3's model is less explicit about the teacher's role. The model is more general (à la Madeline Hunter) than a specific conceptual change-focused model.

The experts had different ways of thinking about the role of activities in elementary science instruction. For T2, activities are the core of the curriculum. The most important aspect of science teaching is that hands-on activities are included. There is much less focus on how the teacher uses those activities to guide classroom discourse and conceptual development. The primary goal of activities is to support the development of positive dispositions and attitudes toward science. P3 emphasizes many functions of science activities; the best activities address multiple goals. The goals he identifies include those of citizenship, personal and social development, cooperative learning, and concept development. In contrast, P1 and T1 emphasize the conceptual goals of activities. In their view activities are selected that provide powerful representations for elementary students. Activities that challenge students' misconceptions and engage them in thinking about the problem at

hand are especially valued. Teachers should use only a few key activities and surround them with rich written and oral classroom discourse to support students in using the activities to undergo significant conceptual change.

The experts also varied in the learning theory they articulated. P1 and T1 had a focused conceptual change view of science learning. Both P2 and P3 had a more eclectic theoretical stance, attempting to integrate constructivist views of learning with discovery, behavioral, and developmental stages views. T2 and T3 did not articulate a particular theory of learning although both seemed confident that student engagement in physical manipulation of objects is an important step in learning. In their views, children discover and internalize ideas through such physical manipulations of objects.

Teacher Education and Teacher Change

The experts seemed to fall into two groups in their visions of the kinds of teacher education needed to support elementary school science teaching. P1, P2, T1, and T3 fall into a group that emphasizes the need for teachers to learn by thoughtful reflection on theory, research, and student learning combined with indepth feedback and coaching as the teacher attempts to integrate theoretical perspectives with classroom teaching. Thus, teachers' conceptions of science teaching and learning are first challenged before they actually start making any changes in their teaching practice. This group emphasizes the importance of thoughtful study of subject matter as an important piece of this model. They suggest that teachers can study science concepts in the context of studying research and their own practice.

P3 and T2 share a different perspective about teacher change. Although they agree with the other experts that teachers need to undergo significant conceptual change about the teaching and learning of science, they propose a more pragmatic approach to teacher change. In their view, teachers learn by

doing. Therefore, teachers should get involved in using new curriculum materials (P3) or developing materials (T2) as a first step in their learning. P3 describes ways in which involvement in implementing his curriculum materials may eventually enable teachers to rethink their views of teaching and learning. T2 describes the goal as helping teachers catch "science fever." Thus, teachers' conceptions of teaching and learning grow out of their attempts to implement a new science curriculum. Both P3 and T2 acknowledge that curriculum materials alone are not sufficient to support this kind of teacher change. Both experts provide teachers with additional support. However, they do not provide the kind of indepth feedback and coaching advocated by experts in the first group.

Curriculum Development

The experts' views about curriculum development were of particular interest since all the experts were involved in some kind of curriculum development work. Their views differ along several different dimensions: the degree to which the development process is research-driven versus teacher-driven, the extent to which the curriculum development process is linked to an instructional model or is eclectic in nature, the nature of evaluation of the curriculum implementation, and the degree to which the process is reality bound.

T1 and P1 share a research-driven view of curriculum development. They see topic-specific research on students' conceptions as a critical starting point of the curriculum development process. They also envision curriculum activities and materials packaged in new ways that better support students' conceptual change Thus, curricular units would provide questions and activities to elicit students' misconceptions, student tasks that challenge their personal theories, explanations that help students link their personal theories to

scientific explanations, and numerous problems and activities in which students can practice using new concepts to develop explanations of everyday phenomena.

Both T1 and P1 have developed sample units of such materials and studied them in use. T1 developed such a unit on light and shadows as part of an intensive inservice project. He would like to see the research experts develop additional units along the same format; he does not have the time and the expertise to develop such units himself for all the units he teaches. P1, in collaboration with colleagues, developed a number of conceptual change-oriented units of instruction as part of his research work. The most recent unit was about matter and molecules and was developed and evaluated collaboratively with sixth grade teachers.

P1 began the development process with careful research on sixth graders' conceptions of matter and molecules. The data included clinical interviews, written tests, and classroom observations. Over a two-year period, P1 and colleagues wrote the materials, studied their impact on student understanding, revised the materials, and again conducted detailed research on students' interpretations of the instruction. Thus, the materials went through several iterations based on feedback from studies of learners and from teacher feedback. P1's model of curriculum development can be characterized as research-driven both in its inception and in its evaluation. The curriculum development process is also tightly tied to a particular model of instruction.

P2 used a similar research-driven model in her heat and temperature unit for middle school students. However, her curriculum development work was more eclectic in nature. She is not driven by a particular model or conception of instruction although the unit she came up with is consistent in many ways with P1's conceptual change model. She sees the development process as driven by a constuctivist framework for thinking about student learning, but she pulls

from a variety of theoretical and research sources including Piagetian developmental psychology and metacognitive studies of learning strategies. Her numerous revisions of the unit parallel those of P1; she studies student understanding in depth as an evaluation of the unit. Like P1, she has been developing, studying, and revising this one unit over a long period of time.

We would characterize P3's curriculum development process as research-based but not research-driven. By that we mean that P3 draws from a variety of lines of research to develop the overall guidelines and criteria for the curriculum. However, at the point of writing the curriculum P3 becomes reality bound: Units are developed rather quickly by writers who may know very little about particular student misconceptions and who may be only superficially knowledgeable about the research base on which the guidelines were based. Thus, writers work within a generic research-based framework, but research is not driving what they create.

Similarly, evaluation of student learning and subsequent revisions of materials are not focused on in-depth research of student understanding. There is some evaluation of student learning but it is not a deep enough analysis to really drive the revision process. P3's process is guided by a generic instructional model (engage, explore, explain, elaborate, and evaluate), but the time constraints and publishing realities have an equally powerful effect on the final product.

T3 and T2 have more of a teacher-driven model of curriculum development. T3's teacher-driven view is based on research about student development of conceptual understandings. T2's teacher-driven view is more reality-based: He wants to inspire teachers to teach more science and believes that by engaging them in doing science and curriculum development work, they will catch science

fever. He views this as a practical first step to get teachers involved with the science curriculum.

Neither T2 nor T3 has a particular model of instruction guiding this development process. T2 uses some general guidelines about student misconceptions and the need for connectedness and usefulness of science concepts. T3 is guided more by finding interesting, manageable activities on topics that elementary teachers like to teach. An instructional model is not a priority in his view of curriculum development, although he does emphasize continual reference to objectives outlined in the California Science Framework (California State Department of Education, 1978).

Implications

There is a striking consensus among these teacher, researcher, and curriculum developer experts that the traditional science curriculum is far from the ideal elementary science curriculum. The experts also share a vision of the ideal that is common in many ways. They all advocate the "less is more" slogan; they all stress connecting science concepts with students' everyday experiences and prior knowledge; they all assert that students need to be much more active in constructing meaning in science classrooms. They agree that elementary science instruction should focus on helping students develop conceptual understandings that they can apply and use in a variety of contexts both in and out of school. The experts share a view that the elementary science curriculum should change and can change. They offer numerous suggestions about how curriculum materials might be redesigned to support students' conceptual development. They agree that it is not the particular content being taught at the elementary level that matters; what matters is that students develop deep understandings of whatever science content they do study. The experts look at science teaching and learning through lenses that are more

similar than different. They all view learning through a constructivist lens to some extent, and they all support some version of a conceptual change of model of instruction.

If this consensus reflects a broader consensus nationwide, then why aren't curriculum materials being developed from this purview? Why do we see so much traditional, didactic science teaching? It could be that this group of experts reflects more consensus than the larger community from which they were drawn. These teachers, for example, stood out among their peers as doing particularly creative and thoughtful work in science teaching. The researchers, although representative of three current perspectives in elementary science instruction (conceptual change, inquiry, and science-technology-society), have had interactions with each other and therefore may share more closely common ideals. In contrast, it does seem that the literature nationwide supports consensus on some of these issues. If that is the case, we can point to several practical and policy factors that are impeding this vision from becoming enacted in many science classrooms.

First, as the experts all pointed out, this vision of the elementary curriculum requires a level of teacher knowledge that most elementary teachers have not developed. To teach for conceptual understanding, teachers will need to make major shifts in their views of science teaching, science learning, and science knowledge. Time is another practical concern. The experts outlined ways in which schools may need to be restructured to provide teachers with the time to become thoughtful and reflective about their instruction. Time is also a factor on the curriculum development end. When the National Science Foundation (NSF) is pushing P3 to develop a unit a month, instead of a unit a year, time becomes a critical limiting factor. Since a unit that is truly research-based cannot be developed in that time frame, we are forced to go with

best guesses and judgments. Research knowledge is also a limited resource. NSF and other granting agencies need to recognize the value of supporting studies of particular students' conceptions of particular subject matter concepts and topics.

This study has implications for teacher development as well as for curriculum development. We were struck by the significant impact of in-depth inservice opportunities that T1 and T3 experienced. Both teachers clearly valued and grew from these relatively long-term interactions with university researchers. We hypothesize that it is at least partly because of these close interactions that we did not detect striking differences between the teachers and the researchers: Both groups were knowledgeable about the research base in science education and had struggled with the implications of that research base for classroom teaching and learning.

T2's experiences with state-level science education policy work seems to have had a different impact. While he is extremely knowledgeable about science objectives and activities, he does not have as clear a vision of what makes science learning difficult for students. He does not seem knowledgeable about the research in science teaching and learning, and this seems to limit his insights into classroom teaching and learning. His analyses of "what works" are limited to the level of student interest and participation and do not probe deeply into the actual understandings that students are developing. Perhaps it is because of this lack of deep analysis of student learning that he is content to advocate hands-on activities as the solution to the problem of elementary science teaching.

What will be needed to make these experts' visions a reality? Perhaps a first step is the kind of consensus building that the National Center for the Improvement of Science Education is providing. The Center recently published a

series of reports about elementary science that summarize the status of elementary science and describe the ways in which research suggests a change in the status quo. However, another piece of this consensus building must include clarification of differences as well as areas of consensus. In this study we have explored both areas of consensus and areas of difference.

The areas of consensus are striking and exciting, but we believe that further exploration of the areas of difference is needed. For example, our science-technology-society representative advocated technology and health as part of his particular curriculum series. We did not get a sense of what he might think about a conceptual change-oriented curriculum that did not include teaching about technology and health. Is this an area where he does not want to say that the content selection is arbitrary? And what about our conceptual change-oriented experts? Is content truly arbitrary in their minds? Would they be willing to incorporate technology and health into their curriculum? Would they be willing to let teachers choose what to teach if it meant that they taught about dinosaurs and biology every year? Where would they draw the line between arbitrariness, teacher choice, and a sound science curriculum? (See Table 4.)

We believe that improved curriculum materials and teacher development opportunities are also critical pieces needed to make these visions a reality. Existing curriculum materials (fact-oriented science textbooks) and short-term make-and-take inservice workshops are woefully inadequate to support teachers in teaching for conceptual understanding. Both preservice and inservice teacher education need to provide opportunities for teachers to change their conceptions of science teaching and science learning and their knowledge of science concepts. This will not be quick learning; it will take time and support and opportunities to move back and forth between study of research and

Table 4

Six Experts' Visions: Areas of Consensus and Disagreement About Ideal Elementary Science Curriculum

AREAS OF CONSENSUS:

Goals	Criteria for Content Selection	Views of Teaching and Learning
-Conceptual understanding and problem solving as higher order thinking	-Arbitrary choices	-Conceptual change/constructivist views of the learner
-Connectedness, coherence	-Related to students' everyday lives/usefulness in explaining real world phenomena	-Eliciting children's explanations as a starting point
-Application/usefulness	-Children's thinking and development (prior knowledge, misconceptions)	-Activities important
-Depth over breadth	-Connectedness/conceptual integration	-Activities that pose discrepant events
	-Multiple representations available--including physical, visual	-New ways of assessing student learning needed--student writing as a valuable assessment tool
	-Teacher interest, teacher knowledge	
	-Conceptually integrated within grade levels	

AREAS OF DISAGREEMENT:

Goals	Criteria for Content Selection	Views of Teaching and Learning
-Relationships among science content, process, and attitude goals	-Key ideas/usefulness within in the disciplines	-Conceptual change view of learner as primary or one of several views of the learner
-Citizenship goals (self-esteem, working in groups, personal and social decision making)	-Research on students' conceptions	-Instructional models--explicit vs. implicit, eclectic vs. conceptual change
-Technology	-Student interest	-Roles of activities--to support positive attitudes, for multiple goals, primarily for conceptual goals
-Health and social issues	-Balancing life, earth, and physical science	
-Self-regulation	-Balancing science, technology, society issues	
-Integration across grade levels	-State guidelines	
-Integration across subject matter	-Exemplary programs	
	-Science process skills	
	-Manageable, enjoyable activities	
	-Organizing concepts should not be unique to science	
	-Integration across grade levels	
	-Integration across subject areas	

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Table 4 (continued)

AREAS OF CONSENSUS:

Teacher Education/Teacher Change	Curriculum Development	Views of Teaching and Learning
-Development of teachers' subject matter knowledge needs to be improved -Teachers need to develop new views of science teaching and learning (go through their own conceptual change) -Curriculum materials are not sufficient to support changing teachers' views of science teaching/learning	-Existing text series (such as Silver Burdett & Ginn) do not support teaching for deep understandings -Improved curriculum materials are needed: -Amount of content and vocabulary must be cut down -Texts could do better job of helping students and teachers connect ideas and see "big picture" -Texts could provide information about student conceptions and students' typical responses to activities, questions	

AREAS OF DISAGREEMENT:

Teacher Education/Teacher Change	Curriculum Development	
-Teachers learn by thoughtful reflection on research and learning combined with "doing"; receive in-depth coaching/feedback during "doing" phase. Study science concepts in context of studying research and own practice. -Teachers learn by doing--new conceptions of teacher, learning, subject matter grow out of implementation of a new curriculum or curriculum development work	-Curriculum development process as research-driven, research-based, or teacher-driven -Use of instructional models in curriculum development--eclectic vs. conceptual change vs. process -Nature of curriculum evaluation and revision -Practicality or ideals	

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theory and practical applications in the classroom. Curriculum materials can become more useful tools for teachers if they explore a few ideas in depth, take students' conceptions seriously as a way of organizing instruction, provide teachers with information about students' misconceptions and difficulties, and include numerous representations and contexts to support students in constructing understanding of concepts.

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Appendix A

Key Features of Ideal Science Curricula

CURRICULUM IMPROVEMENT STUDY

Mission of the Elementary Subjects Center

The Elementary Subjects Center is one of the mission-oriented research and development centers established by the federal Office of Educational Research and Improvement. Our mission is to develop knowledge about effective teaching in five content areas (social studies, science, mathematics, literature, and the arts) at the elementary grade level, especially as it relates to the conceptual understanding and higher order thinking aspects of learning in those content areas. We seek to identify effective strategies for content area teaching that will empower students with knowledge, skills, and dispositions that they can access and use when relevant--both now and in the future, both in and out of school.

The decision to focus on this mission was prompted by several commonly made criticisms of current practice. One is that although our elementary schools seem to be doing a good job of teaching basic knowledge and skills, as indexed by scores on short answer or multiple choice tests, more emphasis may be placed on rote memorization than on meaningful understanding. A second criticism is that insufficient attention is being given to critical thinking, problem solving, and other higher order thinking aspects of content learning. Related to this is the concern that curriculum writers' continuing attempts to accommodate pressures for introduction of new content have enhanced breadth at the expense of depth. The result is that many topics are merely mentioned rather than taught in sufficient depth to develop conceptual understanding. This creates fragmentation. Instead of integrated networks of content structured around key concepts and generalizations, curricula have become clusters of disconnected content that are not organized coherently. Too many students learn only a smattering of relatively unconnected facts and ideas, most of which are soon forgotten. As a result, they end up able to access their learning in usable form only when presented with well-defined problem situations that cue them to do so (e.g., school assignments and tests).

These concerns reflect our views about learning: We believe that knowledge that is not well connected to other knowledge and past experience is transient and thus of limited value. It is generally not available for use in potentially relevant situations outside of the specific contexts in which it is acquired. Knowledge that is richly connected to other knowledge, on the other hand, is much more accessible. Because it is part of a network or structure, this type of knowledge also provides more entry points for subsequent learning, thus influencing the acquisition of new knowledge. The ability to develop relations between new and prior knowledge is facilitated when knowledge already rich in relations is part of the learner's cognitive structure. The importance of connected knowledge has been emphasized by a number of researchers; in fact, some equate connectedness with conceptual understanding.

Purpose of This Study

Our Center's research and development agenda calls for identifying ways to improve on current practice, particularly with respect to the criticisms and concerns described above. In a series of related studies, we plan to develop information about expert opinions on ideal practice, describe the variation in current practice (with emphasis on description of what occurs in classrooms where students are being empowered with accessible and usable learning), formulate and test the feasibility of guidelines for improvement, and test the effectiveness of those guidelines.

During the first phase of this research agenda, we will acquire and synthesize expert opinion about ideal practice in each of the content areas. The Curriculum Improvement Study is part of this effort. In this study we will be gathering information from two types of experts: (a) university professors recognized for their leadership in elementary level science education (and in particular, in methods of designing such education so as to empower students with accessible and usable learning) and (b) elementary grade teachers recognized for the excellence of their science teaching (and in particular, their efforts to ensure that their students are empowered with accessible and usable learning).

Your participation in this study will occur in two parts, each with several subparts. In the first part of the study, which is discussed in this paper, you will outline your ideas about the key features of ideal elementary level science curricula and illustrate these with examples. By analyzing your responses and those of the other experts included in the study, we expect to identify areas of consensus that represent the best current thinking about the ideal features of elementary science teaching.

Thoughts About Ideal Curriculum

We are interested in having you identify what you consider to be the key features of an ideal elementary grades science curriculum. Before getting to specifics, we need to clarify two aspects of our use of the term curriculum, and our intentions in designing this study. It is essential that you understand these two points.

First, although we call this the Curriculum Improvement Study and frequently use the term "curriculum" for convenience in these instructions, we give the term broad meaning. When we ask you to identify ideal features of a curriculum or to critique a curriculum, we mean to include not only the content (knowledge, skills or strategies, values, and dispositions) addressed in the curriculum's scope and sequence, but also everything else in the science program that impacts on students. Specifically, we mean to include the program's overall goals, the content selected for inclusion, the texts and other curriculum materials, the instructional methods, and the methods of evaluating student learning. In conveying your ideas about the features of ideal curricula,

we want you to consider all of these features and the ways that they interrelate to produce effects on the students. You may find it helpful to mentally substitute a term such as "program," "overall approach," or "curriculum-instruction-evaluation combination" for our term "curriculum" as you read through the directions and think about your responses.

Our second clarification concerns the content aspects of ideal curricula. Please bear in mind the breadth versus depth issue and our stress on the importance of (a) empowering students with accessible networks of coherently organized and usable learning and (b) allowing for sufficient development of critical thinking, problem solving, and other higher order applications of this learning. If these goals are to be accomplished, choices must be made; that is, breadth of coverage must be limited to allow for sufficient depth. One cannot address all worthy goals or include all potentially relevant content, instructional methods, activities, assignments, or evaluation methods.

Ideal Curricula

Features of Ideal Curricula

In conveying your ideas about key features of ideal curricula, please begin by reacting to those that we have already described. We have suggested that ideal curricula will be designed to empower students with meaningfully-understood, integrated, and applicable learning that can be accessed and used when relevant in a broad range of situations in and out of school. This implies the following:

(a) balancing breadth with depth by addressing limited content but developing it sufficiently to ensure conceptual understanding;

(b) organizing the content around a limited number of powerful ideas (basic understandings and principles rooted in the disciplines);

(c) emphasizing the relationships between powerful ideas, both by contrasting along common dimensions and integrating across dimensions, so as to produce knowledge structures that are differentiated yet cohesive;

(d) providing students not only with instruction but also with opportunities to actively process information and construct meaning;

(e) fostering problem solving and other higher order thinking skills in the context of knowledge application; thus, the focus is less on thinking processes per se, and more on how to utilize or make use of previously acquired knowledge in new contexts.

Questions for you to Address Relating to Ideal Curriculum

Given the above discussion, we would like you to begin by considering two questions:

1. You may or may not agree with our suggestions about key features of ideal curricula. If you agree with everything we have said, just say so and proceed to Question 2. However, if there is anything about these ideas that you would not fully endorse, please tell us. Do you simply disagree with any of them? Do you partly agree but think that they need to be qualified or rephrased? Are there any that you see as desirable but not important enough to be considered key features? Please address these or any other points of disagreement that you may have with our suggestions about the key features of ideal curricula.

2. Beyond what has already been said in your response to the previous question, and keeping in mind our broad definition of "curricula," what other features would you identify as key features of ideal curricula? List as many such features as you believe are important enough to be considered key features, and elaborate as much as you can.

Curriculum Design Exercises

Now that you have given your ideas about the key features of ideal curricula at the K-6 level, we would like you to apply them in responding to three curriculum design exercises. For these exercises, we will present you with three important goals that are representative of what an elementary science curriculum might address, and for each goal we will ask you to respond to four questions.

Goals to be Addressed

You may find it helpful to approach these exercises as if you were a consultant assisting the staff of a local school. The school has decided to have you address three general goals that are representative of what they are trying to accomplish in their elementary level science program. Because the goals are broad, pervading much of the science content taught at the elementary level, the school wants you to focus your attention on the concept of ecosystem as it relates to each goal. The three goals that you have been asked to address are as follows:

(a) developing an understanding of how living things interact with other living things and with their physical environment.

(b) developing an understanding cyclic, sequential, and evolutionary change as it relates to everyday physical and biological phenomena.

(c) developing a disposition to be open to, yet skeptical of, new and

untested ideas; included under this rubric is developing an appreciation for science as a form of human inquiry, and as a way of satisfying one's puzzlement or curiosity about the world.

As you proceed with the exercise, bear in mind that the school wants you to focus specifically on the concept ecosystem as it relates to the three broad goals listed above. Assume that the school serves a student population that is racially and culturally diverse but neither notably high nor notably low in socioeconomic status, that the students are grouped heterogeneously, that class sizes average about 25, and that the teachers work with adequate but not abundant resources. Also assume that the teachers are fairly well grounded in all the subjects they teach, including science. With these constraints, you could suggest whatever strategies you wish for accomplishing the three goals, but your recommendations should be realistic (e.g., cognizant of the teacher's needs to handle the full range of subject matter areas and to address other major goals even within the science program).

Questions for You to Address for Each Goal

For each of the three goals, please answer each of the following questions:

1. What important understandings or generalizations should be developed in students if the goal is to be accomplished? You may include as many of these as you wish and describe them in as much detail as you wish, although given the focus on the most basic and powerful understandings and generalizations, we expect that you will be able to respond with brief listings of perhaps as many as ten such key understandings or generalizations once you have thought through and organized your ideas. (An example might be helpful: If the overall goal is developing an understanding of how energy changes, a key understanding might be that energy from the sun can be changed into energy stored in food through the process of photosynthesis in green plants.)

2. What sorts of relationships exist among the key understandings and generalizations you have listed? Do they all fit together into a single network? Are two or more of them linked through cause/effect, rule/example, whole/part, or other logical relationships? Do some of them form natural sequences along some common dimension? Feel free to supplement your comments about such relationships with diagrams or other illustrations if you wish to do so.

3. How would you organize these key understandings and generalizations to present them to students? Explain your rationale for this organizational plan (i.e., would it be determined by the logical relationships outlined in your answer to the previous question, or instead by other criteria such as the degree to which the key ideas refer to things that are already familiar to children at particular ages or the degree to which they can be represented in concrete terms). In general, please describe the approach that you would

take in ordering or organizing these ideas in the curriculum, and explain your rationale.

4. Select one of the key understandings or generalizations you have listed and explain in detail how you would propose to develop it at the second and the fifth grade levels. (You may wish to start with the grade you are especially knowledgeable about and use it as a basis for comparison with the other grade. We can help you decide which ideas on your list would be the best ones to use as the basis for this part of the exercise; we are looking for ideas that seem to be at about the right level of generality and to be appropriate for development at both the second grade and the fifth grade level).

   For each grade level, we would like to have you tell us in detail how you would teach the key understanding or generalization. Because it is likely that it will take more than one lesson to teach the understanding, please sketch out your overall instructional plan first, then select for more detailed treatment one prototypic lesson. For this lesson, please address the following: (a) What kind of information would you provide through teacher presentation, through having the students read, or through some other mechanism? (b) What sorts of teacher-student or student-student discourse would occur, and with what purposes in mind? (c) What activities or assignments would be included, and with what purposes? and (d) How would you evaluate student understanding or application of the key idea?

Appendix B

Framing Questions

CURRICULUM IMPROVEMENT STUDY

You will soon receive, under separate cover, teacher editions of the most widely used elementary curriculum series in **science.** We are interested in having you critique this material. As you will recall, this study complements efforts at the Center to describe and analyze expert opinion regarding ideal curricula in each of the content areas. There are two aspects to this part of the study. The first involves responding to a set of framing questions, taking detailed notes that you can later refer to during the interview here on campus. The second involves writing a brief summary of your overall impressions of the curriculum series.

The framing questions are listed below. Please consider each of these in turn as you work through the material. Because these questions will be raised during the interview, there is no need to prepare complete responses. However, as we indicated, it would be helpful if you jotted down ideas during your review. In addition to having you address these specific questions, we are also interested in obtaining your overall impression of the curriculum series. Thus, we would like to have you write a brief, three to five-page summary of your views; this should be prepared after you have had a chance to respond to the framing questions . Feel free in this summary to highlight any issue or concern about which you feel strongly. If there are issues that have <u>not</u> been adequately addressed in our set of framing questions, please raise them in the summary.

<u>Part A: A Broad Sweep Through the Series</u>

These questions are divided into three major sections. In the first section--termed the "broad sweep" section--we want you to use your responses to Part 1 as a starting point. In Part 1, you will recall, we presented three general goals that were said to be representative of what teachers at a particular school are trying to accomplish in their elementary science curriculum. The three goals were as follows:

1. Developing an understanding of how living things interact with other living things and with their physical environment.

2. Developing an understanding of cyclic, sequential, and evolutionary change as it relates to everyday physical and biological phenomena.

3. Developing a disposition to be open to, yet skeptical of, new and untested ideas; included under this rubric is developing an appreciation for science

as a form of human inquiry, and as a way of satisfying one's puzzlement or curiosity about the world.

You provided a thoughtful analysis of these goals, identifying for each a set of key understandings or generalizations that might be developed in students, indicating how these understandings were related, and how they might form the basis for a curriculum in science. (You may have decided to reformulate one or more of the goals; if so, use the reformulated goals and related analysis in responding to the questions raised below.)

In this first section, we want you to draw on the Part 1 analysis to critique the textbook series as whole (i.e., books for grades one to six). Please respond to the following questions:

1. Taking each of the three goals in turn (or those that you have substituted for them), what important ideas or understandings appear to be stressed in the curriculum material? It may be that these ideas or understandings emphasized in the curriculum material differ in some important ways from those that you highlighted in your Part 1 analysis. In what ways are the two sets of ideas similar; in what ways are they different?

2. For each of the three goals, we would like you to select examples that meet the following criteria: (a) an understanding or idea you thought was important that was well treated in the text; (b) an understanding or idea you thought was important that was poorly treated in the text; (c) an understanding or idea emphasized in the curriculum material (but not necessarily by you) that was well treated; and (d) an understanding emphasized in the curriculum material that was poorly treated. What do you like about the examples where understandings are well treated? What is problematic about the examples where understandings are poorly treated?

3. Focusing on the ideas or understandings that appear to be stressed in the material for each of the important but representative goals listed above, please respond to the following questions: (a) Are the connections between ideas made clear so that the material is learned as an organized body of knowledge as opposed to an isolated set of facts and concepts? (b) Are the ideas or understandings represented in multiple ways (e.g., models, metaphors, graphs, charts, pictures)? If so, how do these representations contribute to student understanding?

Part B: Focusing in on Particular Units and Chapters

In this section, we would like you to focus on two units--one at the second-grade level and one at the fifth-grade level. The second-grade book is blue and has Teacher Edition 2 printed on the front. Please attend to Unit 1. This unit includes the following chapters: "Animals of Long Ago," "How Plants Grow," and" Where Plants and Animals Live." The fifth-grade book is orange and has Teacher Edition 5 printed on the front. We want you to focus on Unit 1. This unit includes: "Activities of Green Plants," "Animals Without a Backbone," "Animals With a Backbone," and "Living Communities."

1. What important understandings or ideas are students supposed to derive from having worked through each unit? To what extent are these understandings represented in the stated goals or objectives for the unit?

2. Please critique the material in terms of how adequately it develops the understandings identified above: What is it specifically about the material that helps student understanding of these ideas? What hinders student understanding? What would you do to improve the material in this regard?

3. In what ways are suggested questions, activities, and assignments (including worksheets) likely to contribute to student understanding of important content? What are examples of good activities or exercises? Ones that are good in conception but poorly designed? Ones that are poor in conception and not worth doing? What activities or assignments might you add to bolster student understanding of important content?

4. Does the material provide sufficient opportunity for students to apply the knowledge they are acquiring? To what extent do the questions, activities, and assignments provide occasions for students to talk or write about what they're learning (i.e., beyond short answer responses)? How would you characterize the nature and quality of these occasions?

5. Please carefully note any material or guidelines relevant to student assessment: (a) Are there any pre-assessment activities that help teachers understand students' prior knowledge and understanding before getting into units or chapters? (b) Is there a good match, in your opinion, between what is assessed and the content, activities, and assignments presented in the text? (c) Do the assessments tap the kinds of thinking that you consider important in the classroom? If not, why not? (d) Does the assessment information have clear implications for further instruction--that is, is it useful in helping teachers analyze students' errors and diagnose gaps in students'

knowledge, skill, or understanding? If not, how would you change the assessment procedures so that they do provide this kind of information?

Part C : General Issues

In this final section, we want you to once again evaluate the curriculum series as a whole, considering some important issues not fully addressed in the two previous sections.

1. In the last section, the focus was on student understanding of content. Now we would like you to think more generally about student understanding of science as a discipline. What view of the nature of science do you think students would derive from having worked through this textbook series?

2. What kinds of knowlege is required of the teacher to use the materials appropriately? What support in these areas do the materials provide for teachers?

3. In general, is the series appropriate for all types of students? Would any particular changes be needed if it were to be used primarily with low Socioeconomic status or minority students? If so, what might those changes be? Would it challenge more advantaged students? Does the series offer suggestions for managing and organizing instruction for a diverse group of students?

4. Is important content missing? If so, provide one or two examples. Is some of the content misleading or incomplete and thus in need of reworking? If so, cite one or two examples.

5. One common criticism of textbooks is that they try to cover too much material. If you were asked to reduce the total amount of content by one-third, what would you delete? Why? In what ways might you reorganize the remaining content?

6. Comment on the ratio of factual detail to main ideas or understandings. In general is it about right or does the series err on the side of too little or too much supporting (i.e., factual) detail? What about clutter (e.g., unrelated facts, side issues, intrusions, "mentions")? Is it a problem?